Horizontale en verticale samenwerking in distributieketens met cross-docks

Buijs, Paul

Horizontal and vertical collaboration in distribution networks with cross-docks

Paul Buijs

Publisher: University of Groningen
Groningen, The Netherlands

Printer: Ipskamp Drukkers B.V.
Enschede, The Netherlands

ISBN: 978-90-367-7208-2 (book)
978-90-367-7207-5 (e-book)

rijksuniversiteit
groningen

Horizontal and vertical collaboration in distribution networks with cross-docks

Proefschrift

ter verkrijging van de graad van doctor aan de
Rijksuniversiteit Groningen
op gezag van de
rector magnificus prof. dr. E. Sterken
en volgens besluit van het College voor Promoties.

De openbare verdediging zal plaatsvinden op
donderdag 18 september 2014 om 14.30 uur

door

Paul Buijs

geboren op 10 november 1985
te ’s-Gravenhage

Promotores
Prof. dr. ir. J.C. Wortmann
Prof. dr. I.F.A. Vis

Copromotor
Dr. N.B. Szirbik

Beoordelingscommissie
Prof. dr. R.H. Teunter
Prof. dr. J. van Hillegersberg
Prof. dr. B. Montreuil

Voor mijn ouders.
Hans en Yvon

Contents

Chapter 1.

Introduction

1.1 Setting the scene

Driven by increasingly demanding customer requirements and competitive market conditions, the length and complexity of supply chains have increased considerably over the last decades. Globalization and specialization became popular means to address the relentless need for high-value products at low supply chain costs. Consequently, today's supply chains often consist of many highly specialized, globally distributed partners. Moreover, customers increasingly demand products that fulfil their individual needs, which pressures supply chains to increase their product assortment and reduce product life cycles. In response, supply chains have implemented built-to-order production approaches and adopted inventory reduction policies. With regard to the distribution of products, customers expect a choice from a variety of distribution channels—each with short and reliable distribution lead times. As a result of the above trends, distribution logistics is faced with decreasing load sizes and increasing shipment frequency with ever stricter timing requirements.

The fragmentation of freight flows in distribution logistics is at odds with the increasing need for enhanced sustainability—broadly conceptualized at an ecological, societal, and economical level (Carter and Rogers, 2008; Elkington, 1998). Ecologically, the fragmentation of freight flows has resulted in an increased and inefficient use of heavily polluting logistics resources, such as trucks and warehouses. Often, goods are moved by means of partially empty trailers or sitting idly in warehouses. From a societal point of view, the inefficient use of trucks leads to congestion around urban areas; whereas the fragmentation of freight flows jeopardizes fast and reliable distribution services for customers in rural areas. Moreover, workers in distribution logistics are faced with low job security. Economically, most logistic service providers operate at very thin profit margins. Furthermore, they often lack the means to invest in the innovative logistics solutions and services required to ensure their long-term economic viability. Considering all of the above, there is a strong need for new logistics solutions that enable a sustainable distribution of small loads, at high frequency, with strict timing requirements.

This thesis focuses on the identification and development of new collaborative logistics solutions for the purpose of improving the sustainability of distribution logistics. It relies upon the premise that collaboration can increase the interconnectedness within and between distribution networks and, thereby, improve sustainability. Collaboration among partners acting at successive stages within the same distribution network (often referred to as *vertical collaboration*) renders the possibility to reduce in-process inventory and lead times in distribution logistics. Cross-docking is an acknowledged logistics strategy in that regard.

Being a just-in-time strategy for logistics, cross-docking aims to improve overall distribution network performance (e.g., reduce transportation, material handling, and distribution lead-times) by facilitating a seamless flow of goods from shipper to receiver (Gue, 2007; Vogt, 2010). Traditionally, economies in transportation costs were realized by assembling full truckloads from storage at intermediary logistics facilities. Cross-docking enables the consolidation of small-sized shipments without the need for long-term storage. Inside a cross-dock facility, goods are either moved directly from inbound to outbound trailers or temporarily placed on the ground. Due to the absence of a storage buffer inside the cross-dock, local cross-dock operations are tightly coupled with its inbound and outbound network logistics activities (Vogt, 2010). Therefore, effective cross-docking necessitates a holistic supply chain orientation, in which all supply chain partners involved in the cross-docking operations closely collaborate to facilitate the synchronization of inbound, internal, and outbound logistics operations at the cross-dock (Napolitano, 2000). Such collaboration requires sophisticated information technology and planning tools

(Apte and Viswanathan, 2000). The tools and technologies to support local cross-dock operations have been recently developed. Solutions to facilitate the synchronization of the internal operations with the inbound and outbound logistics activities are not yet available. This thesis is concerned with the identification of new solutions in that regard and takes the first steps towards their implementation in practice.

The sustainability of distribution logistics can be further improved by increasing the interconnectedness between distribution networks. Between-network interconnectivity is enabled by collaboration among companies that operate at the same stage of the supply chain (often referred to as *horizontal collaboration*). Horizontal collaboration may involve proximate or distant competitors and can occur at each stage of the supply chain, e.g., among the shippers, carriers, or receivers of goods. Moreover, it can be coordinated by one of the horizontally collaborating companies or orchestrated by an external party, such as a logistics service provider (Hingley *et al.*, 2011; Zacharia *et al.*, 2011). In this thesis, the focus is on horizontal collaboration among road-freight carriers, where the collaborative efforts are coordinated by the participating carriers themselves. From the perspective of the carriers, the decreased volume and increased frequency of shipments is often enforced by the shippers of goods, i.e., the shippers are often the most powerful parties in the distribution network. A carrier is then faced with the challenge of sustainably executing the operations that emerge from the shippers' increasingly demanding distribution logistics requirements. For an individual carrier, the flows of goods are often too thin to transport goods in fully loaded trailers. By means of horizontal collaboration, several carriers can identify and exploit opportunities to bundle goods and thereby enhance sustainability (Cruijssen, 2012). This thesis identifies challenges and opportunities related to the planning and control of such collaborative transport operations and proposes a solution approach supporting joint route planning.

Aspects of the above research topics are addressed in the literature of multiple academic disciplines. The design and evaluation of solution approaches for the planning and control of collaborative logistics operations—both horizontally and vertically—fall within the remit of Operations Research. Issues regarding the exchange of information required for the proposed planning and control approaches, and crucial for the success of collaborative practices, are covered in Information Systems research. Organizational and management aspects of collaboration are part of Supply Chain Management research. This thesis adopts a multi-disciplinary research approach in identifying and developing new collaborative logistics solutions—integrating concepts from Operations Research, Information Systems, and Supply Chain Management.

1.2 State-of-the-art

After setting the scene above, this section highlights the academic state-of-the-art in horizontal and vertical collaboration in distribution logistics. First, this section sets out definitions for horizontal and vertical collaboration, which will be used throughout the thesis. Plainly stated, collaboration refers to the situation where two autonomous companies jointly plan and execute their operations with the aim to realize a higher performance than they could have achieved in isolation (e.g., Lambert *et al.*, 1998; Simatupang and Sridharan, 2002). Collaboration between companies that perform consecutive value-adding activities in serving roughly the same end-consumers is referred to as vertical collaboration (Barratt, 2004). The topic of vertical collaboration is vividly discussed in the supply chain literature, see, e.g., Power (2005) and Van der Vaart and Van Donk (2008) for overviews thereof. The synchronization of inbound, internal, and outbound logistics operations at cross-docks is relatively unexplored. A thorough state-of-the-art analysis on research in that area presented in Chapter 4 and hence not further elaborated here.

Horizontal collaboration is defined as "*identifying and exploiting win-win situations among companies that are active at the same stage of the supply chain*" (Cruijssen *et al.*, 2007b). As opportunities to improve the interconnectedness within distribution networks through vertical collaboration are increasingly being seized, horizontal collaboration provides a means to further improve the performance and sustainability of distribution logistics. Accordingly, the topic of horizontal collaboration is at the forefront of many on-going research initiatives. Internationally, the EU FP7 project CO3 and the Physical Internet initiative are the most notable research endeavors. The Physical Internet initiative aims to "*design a system to move, store, realize, supply and use physical objects throughout the world in a manner that is economically, environmentally and socially efficient and sustainable*" (Physical Internet Manifesto, 2012). It exploits the digital internet as metaphor to propose a vision for innovations that can fundamentally change the unsustainable way in which products are currently transported, handled, stored and produced around the world (Montreuil, 2011). The interconnectedness of logistics services is considered key in the physical internet research projects (e.g., Sarraj *et al.*, 2014, Meller *et al.*, 2012). The CO3 project studies the role of a neutral party that specializes in developing and managing collaborative practices between distant or proximate competitors. It aims to develop legal and operational frameworks to enhance the bundling of freight flow between shippers and carriers (Cruijssen, 2012).

In The Netherlands, several on-going research initiatives address horizontal collaboration in distribution logistics. The notion of *cross-chain control centers* (4C) is at the root of most of these initiatives. A 4C is defined as an orchestrating entity that coordinates flows of physical goods, information, and cash across multiple supply chains (Dinalog, 2014). The application of 4C is aimed at enabling economies in scale and scope by means of facilitating within and between supply chain collaboration. It is considered to be a primary means to improve the sustainability of the Dutch logistics sector in general (Topteam Logistiek, 2012). The *4C4More* project studies the role of 4C in improving the efficiency of transportation and warehousing services in a business-to-business setting. It considers business models and IT support for 4C as well as its implications on supply chain finance and planner productivity. *4C4D* focuses specifically on the bundling of freight flows bound for urban areas. The project *cross-chain order fulfilment* considers 4C to improve the last mile delivery of internet sales in a business-to-consumer setting. Due to the relatively early stages of the above research initiatives, few academic papers about these projects have been published thus far.

This thesis builds upon and extends the work of Mason *et al.* (2007), who describe three cases illustrating how transportation can be improved by means of vertical and horizontal supply chain collaboration. Besides Mason *et al.* (2007), few academic papers study collaboration in the transportation and distribution stages of the supply chain (Fabbe-Costes *et al.*, 2009; Selviaridis and Spring, 2007; Stefansson, 2006). Literature addressing horizontal collaboration among road-freight carriers is even scarcer (Cruijssen *et al.* 2007b). The papers that do exist have primarily proposed mathematical models to support workload allocation among collaborating carriers and to determine how collaborative benefits can best be shared (e.g., Berger and Bierwirth, 2010; Krajewska *et al.*, 2008). Existing empirical research has considered how and why carriers engage in horizontal collaboration from a strategic and tactical perspective (Albers and Klaas-Wissing, 2012; Cruijssen *et al.*, 2007a; Schmoltzi and Wallenburg, 2011; Wallenburg and Raue, 2011). Thus far, no empirical papers have addressed operational aspects of horizontal collaboration among freight carriers.

1.3 Research objective

Owing to the above challenges and opportunities in current practice and the limitations of academic literature, the following research objective is formulated:

> *Conceptualize horizontal and vertical collaboration in distribution networks with cross-docks and derive solution approaches for the challenges and opportunities therein.*

A primary objective for this thesis is to address horizontal and vertical collaboration from a multi-disciplinary perspective—including concepts from Operations Research, Information Systems, and Supply Chain Management theory. The thesis aims to set out broad conceptualizations for horizontal and vertical collaboration in distribution networks with cross-docks. Specifically, the thesis provides a framework for joint operational planning and control among horizontally collaborating road-freight carriers. With regard to vertical collaboration, the thesis develops a framework for the synchronization of local cross-dock operations with its inbound and outbound distribution network logistics. Another objective of this thesis is to explain the challenges and opportunities for research and practice associated with horizontal and vertical collaboration in distribution networks with cross-docks. Lastly, the thesis aims to derive solution approaches for horizontal and vertical collaboration based on the challenges and opportunities identified in the conceptualization phase and make first steps towards the implementation of those solutions.

1.4 Research approach

Strategies for vertical and horizontal collaboration are vividly discussed in the supply chain literature. Nonetheless, understanding how collaboration can be applied to enhance the interconnectedness within and between distribution networks with cross-docks is rather limited—as will be elaborated in the remainder of this thesis. Accordingly, the research presented in this thesis is characterized as exploratory. The general research approach and objectives for each of the studies in this thesis are highlighted below. A more elaborate introduction of the particular research questions and a discussion and justification for the research methods adopted to answer those questions are included in each of the corresponding chapters.

The second and third chapter of the thesis describe empirical studies on horizontal collaboration between autonomous road-freight carriers. Chapter 2 aims to complement prior empirical research findings on strategic and tactical aspects of horizontal carrier collaboration with understanding about operational decision-making aspects. More specifically, the aim is to conceptualize operational planning and control of autonomous carriers in collaborative transportation networks and identity the challenges faced by carriers in that regard. The initial research findings triggered particular research interest in how the integration of different types of IT applications influences joint operational decision-making. Empirical evidence is gathered by means of a multiple-case research design (Yin, 1994) with cases at the planning departments of road-freight carriers operating in collaborative transportation networks throughout Europe.

Chapter 3 describes an illustrative case study at a Dutch logistics service provider. The case focuses on a collaborative transport network operated by two autonomously managed business units. Whereas Chapter 2 explains the role of IT in collaborative transport planning, Chapter 3 studies the practice of Operations Research in that regard. To this end, the transport planning problem of the two business units is studied in detail by conducting interviews, observations, and operational data analyses. Moreover, Operations Research literature is reviewed to define the academic state-of-the-art in the routing problem underlying collaborative transportation networks. The academic state-of-the-art is then compared to the real-world planning problem of the case in order to identify opportunities for future research and development in collaborative transport planning. A selection of these opportunities is addressed in Chapter 3 by proposing and evaluating new collaborative planning procedures. Experiments are conducted to evaluate the appropriateness of each alternative using a data set with one year of operational data.

The fourth and fifth chapter of the thesis address aspects of synchronization in distribution networks with cross-docks. Chapter 4 describes a classification of cross-docking research and the development of a framework for synchronization in cross-docking networks. Papers proposing decision models for the design and/or coordination of cross-docking operations are classified according to a new general classification scheme. The classification scheme is developed by identifying all individual cross-docking decision problems from existing literature and clustering them into six problem classes. Classifying the papers results in an understanding about the information needs for each problem class, i.e., considering the inputs and outputs of the decision models proposed in literature. Based on this understanding a framework is developed that specifies the interdependencies between the different cross-docking problem classes. The chapter provides an illustration of how the proposed research classification and framework can be used to identify cross-docking synchronization problems, i.e., appreciating the interdependencies between local and network-wide cross-docking operations.

Motivated by the research classification presented in Chapter 4, Chapter 5 presents a simulation study on the interdependencies between local and network-wide cross-docking operations. The objective of Chapter 5 is to increase understanding of these interdependencies and explore how they can be addressed in future cross-docking research and practice. A study to these interdependencies requires an analysis of the overall cross-docking network, for which the variability, interconnectedness and complexity inherent to such networks are to be acknowledged. Accordingly, a simulation research approach is adopted. The simulation study considers the case of a large international grocery retailer—modeling the current operations at one of its cross-docks as well as the inbound and outbound logistics activities. Furthermore, a change in the planning of local cross-dock operations and a change in the distribution network design and planning of inbound trailers is proposed and modelled. The aim of the study is to provide quantitative empirical evidence illustrating the impact of a typical network re-design and a change in distribution network planning on cross-docking performance—considering a range of performance indicators frequently used in practice. The performance improvements are compared against the impact of the change in the planning of local cross-dock operations.

1.5 Structure of the thesis

Figure 1.1 displays the overall structure of the thesis by placing the individual research projects described above into context. The core of the thesis is formed by four chapters. Chapters 2 and 3 explore the area of horizontal collaboration among autonomous freight carriers; Chapters 4 and 5 the area of vertical collaboration in distribution networks with cross-docks. Both research areas are first addressed by means of a conceptualization-oriented study to provide a theoretical foundation for a highly relevant, yet heretofore understudied theme of management problems. Each conceptualization-oriented study is followed by a solution-oriented study. The aim of those studies is not to formulate a model for a well-defined isolated sub-problem and then analytically find an optimal—or near-optimal—solution. Rather, the research efforts are geared towards identifying new, generalizable problems that are thoroughly anchored in current practice. The aim is to understand how those problems emerge and behave in their rich context and to specify which types of solutions are needed. In order to substantiate the proposed solution-paths, illustrative heuristics are developed and tested using extensive data sets from industry. Chapter 6 summarizes the main contributions from each chapter and sets out a vision for future research in the context of this thesis.

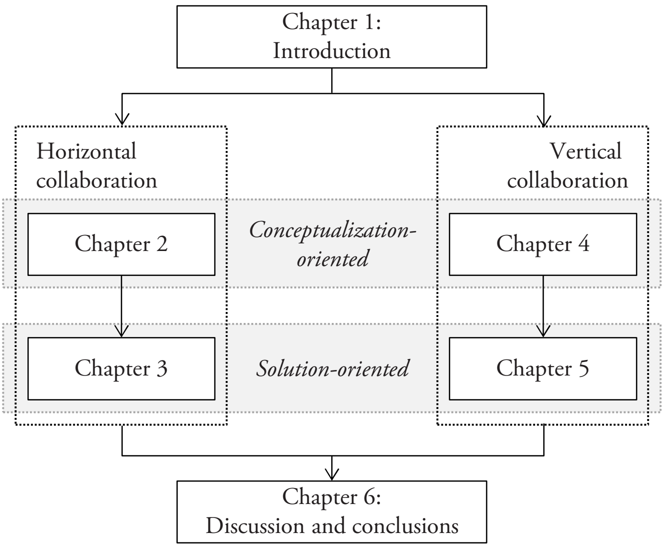

Figure 1.1: Structure of the thesis

1.6 Research deliverables

In addition to this PhD thesis, the research resulted in several other deliverables. Firstly, earlier versions of the text in Chapters 2-5 are published, or in the process of being published, in peer-reviewed journals:

- Chapter 2 is published as: Buijs, P., & Wortmann, J. C. 2014. "Joint operational decision-making in collaborative transportation networks: The role of IT" *Supply Chain Management: an International Journal 19(2)*: 210–220.
- Chapter 3 is submitted to a journal: Buijs, P., Veenstra, M., Lopez, J. A., & Roodbergen, K. J. "Intensifying horizontal collaboration to improve transport efficiency at a logistics service provider Fritom".
- Chapter 4 will be published as: Buijs, P., Vis, I. F. A., & Carlo, H. J. 2014. "Synchronization in cross-docking networks: A research classification and framework" *European Journal of Operational Research* (in press).
- Chapter 5 is submitted to a journal: Buijs. P., Danhof, H. W. & Wortmann, J. C. "Exploring the interdependencies between local cross-dock and distribution network logistics".

Furthermore, the research resulted in another published journal paper, a book chapter, and two papers in conference proceedings:

- Meyer, G. G., Buijs, P., Szirbik, N. B., & Wortmann, J. C. 2014. "Intelligent products for enhancing the utilization of tracking technology in transportation" *International Journal of Operations & Production Management 34(4)*: 422–446.
- Buijs, P. & Vis, I. F. A. 2014. "Comparing industry and academic perspectives on cross-docking operations" In *Material Handling Research 2014* (in press).
- Buckingham, C. D., Buijs, P., Welch, P. G., Kumar, A. & Ahmed, A. 2012. "Developing a cognitive model of decision-making to support members of hub-and-spoke logistics networks" In *Proceedings of the 14th International Conference on Modern Information Technology in the Innovation Processes of the Industrial Enterprises* (pp. 14–30).
- Buijs, P., Szirbik, N. B., Meyer, G. G. & Wortmann, J. C. 2012. "Situation Awareness for Improved Operational Control in Cross Docks: An Illustrative Case Study" In *Information Control Problems in Manufacturing 14(1)*: 1196–1201.

Chapter 2.

Joint operational decision-making in collaborative transportation networks: The role of IT

2.1 Introduction

The value of collaboration in the supply chain is widely recognized by researchers and practitioners. In recent years, researchers have emphasized the important role of freight carriers in buyer-supplier collaboration (e.g., Fabbe-Costes *et al.*, 2009; Gotzamani *et al.*, 2010; Huemer, 2012; Stefansson, 2006). Driven by the increasing need to provide competitive transportation services, carriers have not only participated in buyer-supplier collaboration, but also formed collaborative transportation networks with distant or proximate competitors (Cruijssen *et al.* 2007a). In general, supply chain collaboration among peers is called horizontal collaboration (Barratt, 2004). While acknowledging the important role of carriers in buyer-supplier collaboration, this chapter considers horizontal supply chain collaboration, focusing specifically on joint operational decision-making among autonomous freight carriers in collaborative transportation networks.

Although much has been written about supply chain collaboration, there is a lack of understanding about two aspects within our research context. Firstly, empirical research primarily considered strategic and tactical aspects of horizontal collaboration, such as the selection of partner carriers and the creation of governance structures (Cruijssen *et al.*, 2007a; Schmoltzi and Wallenburg, 2012). Suitable partnerships and governance structures are of limited value, however, if they are not complemented with appropriate operational planning and control procedures. To our knowledge, empirical research in that regard is scarce. Secondly, the precise role of information technology (IT) in supply chain collaboration is not yet really understood (Zhang *et al.*, 2011) and distinctive technological characteristics of different types of IT are hardly addressed in supply chain literature. Owing to these limitations, this chapter addresses the following research questions:

> ***RQ1****: How can operational planning and control of autonomous carriers in collaborative transportation networks be conceptualized and what challenges do carriers face in that regard?*
>
> ***RQ2****: Which specific IT applications are available to facilitate operational planning and control of carriers in collaborative transportation networks and what is their perceived contribution?*

This chapter is organized as follows. Section 2.2 reviews related work and motivates the research presented in this chapter. Section 2.3 details our exploratory and explanatory case study methods. Based on the exploratory case study findings, Section 2.4 sets out a conceptual foundation for horizontal collaboration among carriers, introduces the main challenges collaborating carriers face with operational planning and control, and presents a comprehensive overview of the available IT applications. Section 2.5 introduces the explanatory cases. Subsequently, a typology for IT applications is proposed in Section 2.6. The typology is used to reflect on the case findings and explain why autonomous carriers face challenges with horizontal supply chain collaboration despite the broad availability of local and inter-organizational IT applications. The chapter is concluded in Section 2.7.

2.2 Related work and research motivation

2.2.1 Supply chain collaboration in transport and logistics

Much has been written about collaboration in the supply chain (e.g., Power, 2005; Van der Vaart and Van Donk, 2008), primarily on the relation between suppliers and buyers of goods. Supplier-buyer collaboration is often called *vertical* supply chain collaboration (Barratt, 2004); where the term vertical refers to the sequential value-adding activities at different stages of the supply chain. Since suppliers and buyers are often physically connected by means of a freight transportation stage, carriers fulfilling the transportation function are critical for the success of vertical supply chain collaboration (Stank and Goldsby, 2000). Until recently, however, supply chain literature took the transportation stage for granted and hardly addressed the role of the carriers in supplier-buyer collaborations (Fabbe-Costes *et al.*, 2009; Selviaridis and Spring 2007; Stefansson, 2006).

In addition to their role in vertical supply chain collaboration, carriers may engage in *horizontal* collaboration (Mason *et al.*, 2007). Horizontal collaboration is defined by Cruijssen *et al.* (2007b) as *"identifying and exploiting win-win situations among companies that are active at the same stage of the supply chain"*. In a transportation context, horizontal collaboration enables carriers to gain access to complementary resources (Carbone and Stone, 2005; Lemoine and Dagnaes, 2003) and deploy their resources more effectively (Mason *et al.*, 2007). Carriers consider horizontal collaboration as an opportunity to increase productivity, reduce costs, improve service levels, and strengthen their market position (Cruijssen *et al.*, 2007a; Schmoltzi and Wallenburg, 2011).

Thus far, empirical research has primarily considered how and why carriers develop horizontal networks from a strategic and tactical perspective. The literature on operational aspects of horizontal collaboration in transportation is still in its infancy. Research in that area has primarily proposed mathematical decision models to support workload allocation among collaborating carriers and to determine how collaborative benefits can best be shared (Berger and Bierwirth, 2010; Krajewska *et al.*, 2008). However, these models rely on strong assumptions regarding the operational context and availability of information. In particular, the exchange of information among collaborating carriers is crucial for the success of the proposed decision models, yet the required IT infrastructure is ignored. Applications of these decision models are, therefore, not widespread in practice.

2.2.2 The role of IT

In a broader logistics and transportation research context, the importance of IT in facilitating supply chain collaboration is frequently emphasized. Most case research in this area studied the deployment and use of IT applications facilitating collaboration by means of inter-organizational information exchange. Pramatari (2007), for example, provides an overview of collaborative supply chain practices and shows how the underlying enabling technologies have evolved. Esper and Williams (2003) provide case examples detailing the supporting and enabling roles of IT in collaboration between suppliers, carriers, and buyers. Survey-based research on the relationship between IT and supply chain collaboration often focuses on a single IT application or uses aggregated measures for IT (Zhang *et al.*, 2011). Evangelista *et al.* (2012) consider a wider range of IT applications in their exploratory survey, which indicates a positive relation between IT adoption and the performance of logistics service companies. The authors note that the qualitative insights regarding this relation are rather limited.

In general, understanding about the precise role of IT in this supply chain collaboration is limited. For instance, little is known about which combinations of IT applications may facilitate collaboration in a logistics and transportation setting and how those applications should be integrated (Perego *et al.*, 2011). A notable exception is found in Mason *et al.* (2003), who recommend integrating different IT applications to enable the integration of the warehousing and transportation functions in the supply chain. However, the authors remain silent on how those applications should be integrated from a technological perspective.

Several IT typologies are proposed with the aim to advance our understanding on the—potentially diverse—roles of IT in facilitating supply chain collaboration. Auramo *et al.*'s (2005) typology distinguishes three functional roles for IT in the supply chain: transaction execution, collaboration and coordination, and decision support. Closs and Savistkie (2003) propose a segmentation of IT into an internal and external dimension. The segmentation is based on the ability of a particular IT application to facilitate interdepartmental communication and collaboration (i.e., the internal dimension), or enable information exchange between supply chain partners (i.e., the external dimension). Marchet *et al.* (2012) classify IT for logistics and transportation according to four important application domains: transportation management, supply chain execution, field force automation, and fleet management. Focusing on inter-organizational IT, Kärkkäinen *et al.* (2007) propose a typology that distinguishes types of IT applications according to their specific purpose in sharing and processing information across organizational boundaries: transaction processing, supply chain planning and collaboration, and order tracking and delivery coordination.

We note that the above typologies distinguish IT applications according to their specific purpose in supply chain collaboration. Technological characteristics of IT are generally ignored—although they may dominate challenges with supply chain collaboration. In IT research, typologies do classify applications according to technological characteristics, such as response time for queries and the nature of the databases (e.g., Helo and Szekely, 2005). A well-known technology-oriented typology distinguishes between transactional and decision support applications. This distinction is found in most Information Systems textbooks (e.g., Laudon and Laudon, 2010). Despite the broad recognition for the value of IT in supply chain literature, technological aspects of IT applications are seldom discussed.

2.2.3 Research motivation

Our research is primarily motivated by two limitations in the above literature. Firstly, the freight transportation stage is not often considered in supply chain literature. In particular, empirical research on operational aspects of horizontal collaboration among carriers is scarce. Secondly, little is known about the precise role of IT in horizontal carrier collaborations. The literature hardly addresses distinctive technological characteristics of different types of IT. Accordingly, recent conceptual papers considering the role of IT in supply chain collaboration—either vertically or horizontally—provide little explanation for the apparent challenges at an operational decision-making level.

2.3 Methodology

According to the above research motivation—and in line with methodological remarks from Miles and Huberman (1994), Voss *et al.* (2002), and Yin (1994)—we consider a case study approach most appropriate for our research endeavor. The research presented in this chapter consists of an exploratory and an explanatory phase. The same empirical context and unit of analysis are used in each phase. Collaborative transportation networks constitute the *empirical context* of this research. In particular, we study groups of collaborating, yet autonomous road-freight carriers in the less-than-truckload industry. In this setting, small and medium-sized carriers often collaborate with each other to gain sustainable competitive advantage (Klaas-Wissing and Albers, 2010). All carriers in our study operate a cross-dock, which enables the consolidation of less-than-truckload shipments by redirecting them to their cross-dock. Within this empirical context, the *unit of analysis* is the autonomous decision-making unit responsible for the planning and control of transportation. We study these decision-making units at an operational level.

2.3.1 Exploratory phase

During the exploratory phase, the data to answer our research questions is collected by means of a multiple-case research design for which 7 cases are selected based on *literal replication*, i.e., with the expectation to find similar results across cases (Yin, 1994). Data is collected according to a case study protocol[1] to enhance research reliability (Yin, 1994). The data collection methods include case visits, semi-structured interviews, and company website information—with due attention being given to triangulation. The case study protocol consists of case and interviewee selection criteria as well as a scheme for semi-structured interviews. The interview scheme is structured based on the theoretical framework for managing operations in transportation networks with cross-docks as proposed in Chapter 4. It covers, among others, the decision-making processes related to the planning and control of transportation and within-facility operations. Follow-up questions focused on the information needs and various IT applications used to support these processes. The interviews lasted between 45 and 75 minutes and were fully recorded and transcribed. Surprising outcomes of the interviews and additional questions that arose during the data analysis were summarized and sent to the interviewees for verification and explanation.

Following the procedures outlined by Miles and Huberman (1994) and Voss *et al.* (2002), we first developed a detailed write-up for each case (structured according to the case study protocol). Next, we further broke down case study data by means of within-case analyses. Data from each case was re-structured according to the planning and control of internal cross-dock operations, the structure of the

[1] *For the sake of brevity, the protocol is not included in this thesis; however, it is available from the author upon request.*

collaborative transportation network, the planning and control of transportation, and the use of IT for operational planning and control. Lastly, we searched for cross-case patterns for each of the above groups. The main research findings from the cross-case analysis are presented in Section 2.4.

2.3.2 Explanatory study

When conducting case research, it is not uncommon for the research questions to evolve over time (Voss *et al.*, 2002). In this study, the exploratory research results triggered further interest in joint operational decision-making in collaborative transportation networks and the integration of different IT applications. The research question in the explanatory study is an extension of RQ1 and RQ2 and investigates in more detail *which combinations of IT applications are used for joint operational planning and control in collaborative transportation networks, how those applications are integrated, and what the effects of IT integration are on joint operational decision-making.*

During the explanatory phase, empirical data is collected by means of an embedded multiple-case research design for which 2 collaborative transportation networks were selected based on literal replication (Yin, 1994). Within each network, we studied multiple autonomous decision-making units. The focus in the first case was on two autonomous business units that collaboratively operate a regional transportation network in The Netherlands, Belgium, and Luxembourg. The facilities of both business units were visited to observe the planning and control of transport and cross-dock operations. Moreover, semi-structured interviews were held with the operations director and the IT manager. Both business units allowed unrestricted access to all operational data over a period of 18 months.

The focus in the second case was on a collaborative transportation network in the United Kingdom, with a single hub and around 150 autonomous carriers. During a period of 2.5 years, we visited 16 carriers to conduct semi-structured interviews with regard to operational planning and control decisions. Collectively, the 16 carriers reflect the full range of carrier types affiliated with the hub, i.e., in terms of their size, the proportion of their total freight volume they send through the collaborative network, and their distance to the hub. In addition, we frequently visited the hub, from which the collaborative transportation network is coordinated, for open discussions with the IT director and the manager of IT development. The hub operations were observed three times, during which there was ample time for discussions with the operations managers to probe beyond the responses of IT management. The case company allowed unrestricted access to data specifying all operational transactions of freight in the collaborative transportation network over a period of 5 years.

Similar to the exploratory phase, we first developed a write-up for each case and further broke down case study data by means of within-case analyses. Data from each case was re-structured according to the collaborative transportation network structure, the key joint operational decision-making processes, the IT infrastructure, and the issues with joint operational planning and control. The within-case findings are presented in Section 2.5. Moreover, we searched for cross-case patterns. The main research findings from the cross-case analysis are presented in Section 2.6.

2.4 Exploratory case findings

Based on the exploratory case findings, this section first presents our conceptualization of operations in collaborative transportation networks. Subsequently, we discuss the operational planning and control decisions of autonomous carriers and provide a comprehensive overview of the available IT applications.

2.4.1 Conceptualizing collaborative transportation network operations

The carriers participating in this study are small or medium-sized companies that offer less-than-truckload transportation services from and to a wide range of countries in Europe (see Table 2.1). With regard to the execution of the transportation services, Table 2.1 distinguishes between *specialization* and *collaboration* areas. Collection and delivery locations within the specialization area of a carrier are served by means of transportation resources that are planned and controlled fully by the focal carrier; whereas locations outside the specialization area are often served in collaboration with a partner. Efficiently consolidating shipments with a location outside the specialization area is generally not possible due to a limited concentration of collections and deliveries. If partners can be found that specialize in exactly those areas, collaborating with these partners increases the concentration of collections and deliveries within each partner's specialization area.

Table 2.1: Transportation services

Case	Size (turnover)	Specialization area	Collaboration area
1	Medium-small (€10-25m)	NL, DE	NL, DE, BE, LU, S-EUR
2	Medium (€25-50m)	NL, BE	EUR
3	Small (€2-10m)	NL, BE, LU	NL, BE, LU, DE, S-EUR
4	Medium (€25-50m)	NL, IT, FR, GR	NL, EUR
5	Medium (€25-50m)	NL, DE, AT, CH	NL
6	Small (€2-10m)	S-EUR	NL, EUR
7	Medium-small (€10-25m)	NL	NL

Notes *– AT: Austria, BE: Belgium, CH: Switzerland, DE: Germany, EUR: Europe, FR: France, GR: Greece, IT: Italy, LU: Luxembourg, NL: The Netherlands, S-EUR: Southern Europe*

Considering a collaborative transportation network with two autonomous carriers, Figure 2.1 shows the potential routes for an individual shipment from collection to delivery location. A first distinction can be made between direct and in-direct transportation routes. In the less-than-truckload industry, a single shipment is generally so small that dedicating a trailer to it is seldom justified. Therefore, instead of moving partially empty trailers between many collection and delivery locations, shipments from multiple adjacent collection locations are consolidated into full trailer loads on-route to a cross-dock. At the cross-dock, the collected shipments are unloaded from the trailers and recombined based on their delivery location. In case the additional mileage inherent to redirecting a shipment to a cross-dock is not justified (e.g., due to relatively large shipment size or when the cross-dock is located far out of the route) the shipment can be transported without visiting the cross-dock.

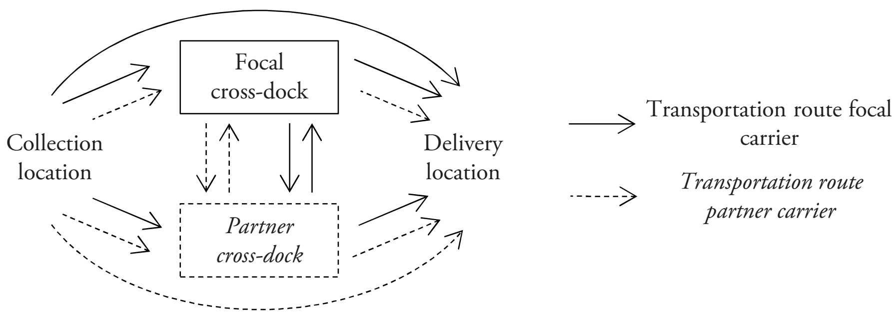

Figure 2.1: Possible transportation routes for an individual shipment

Figure 2.1 also distinguishes multiple options to split (parts of) the transportation between two collaborating carriers. Firstly, a shipment can be completely subcontracted to a partner. In the remainder of this section we do not consider completely subcontracted shipment. This scope allows us to define *collaborative transportation* as the operations where two or more carriers are actively involved in the transportation of a shipment. Collaborative transportation often takes place when either the collection or the delivery location cannot be reached efficiently from the focal cross-dock. The exploratory case study results indicate that most collaborative transportation involves transshipments at the focal *and* the partner cross-dock. Nonetheless, various other collaborative transportation routes are possible. The focal carrier can, for example, collect a shipment and carry it to the cross-dock of a partner. That partner is then responsible for the final delivery.

Aggregating the potential transportation routes of individual shipments, we define two types of transportation routes in collaborative transportation networks: collection and delivery routes (hereafter referred to as *C&D routes*) and *line-haul routes*. A C&D route often stops at many collection and delivery locations in succession. These locations correspond to the origin or final destination of a shipment as specified by the customer. A line-haul route is dedicated to the transportation of shipments from one cross-dock to another and is characterized by a limited number of stops.

2.4.2 Operational planning and control

Operational planning and control in collaborative transportation networks is concerned with two types of shipments. The first type is referred to as *single-party shipments*, which are fulfilled completely by the focal carrier. In this chapter, we focus on the second type of shipments, which are fulfilled collaboratively. Collaborative transportation involves a physical transaction of shipments from one collaborating party to another. Table 2.2 shows how the corresponding exchange of shipments is managed across the cases. A distinction is made between *ad hoc* collaboration and *long-term* collaborative arrangements. In ad hoc collaboration, the partner's cross dock is considered as an ordinary collection or delivery location and is merged with the planning of C&D routes. In long-term collaborative arrangements, the exchange of shipments often relies on tactical agreements.

Table 2.2: Operational planning and control of collaborative transportation

Case	Ad hoc collaboration	Long-term arrangements (local)	Long-term arrangement (international)
1	C&D routes	Line-haul	Line-haul
2	C&D routes	-	Line-haul
3	C&D routes	Line-haul	Cross-dock collection and delivery
4	-	Line-haul	Line-haul and C&D routes
5	-	Line-haul	-
6	-	Cross-dock collection and delivery	Cross-dock collection and delivery
7	C&D routes	-	-

Table 2.2 shows that collaborating carriers typically exchange shipments by means of a line-haul. The planning department of the focal carrier decides each day which shipments are fulfilled completely with self-owned resources and which deliveries are subcontracted to partner carriers—and hence allocated to the line-haul route. The typically fixed capacity on a line-haul route can be extended by allowing additional shipments to be exchanged by means of C&D routes (Case 4). Instead of a line-haul, the focal cross-dock can be daily visited by a partner carrier collecting and delivering shipments (Cases 3 and 6).

In our cases, detailed operational planning and control of collaborative transportation is not done jointly, but done by each party individually. The least profitable collections and deliveries from the perspective of the focal carrier are often subcontracted to a partner. For the subcontracted part of the transportation, the focal carrier entrusts its partner with the detailed operational planning and control. When disturbances occur, the involved partners apply a locally-oriented control approach. Consequently, control decisions are often pushed from partner to partner and the, mostly negative, effects on operational performance cascade through the collaborative transportation network. Carriers regularly face unexpected events imposed by control decisions made by partners at a preceding stage of transportation.

2.4.3 Available IT applications

Table 2.3 presents a comprehensive overview of the IT applications available in collaborative transportation networks. Several IT applications are implemented to support the operational planning and control of the focal carrier's C&D routes. A first group of IT applications in that regard is aimed primarily at managing information. Transport Management Systems (TMS) are used to capture, process, store, and retrieve information about shipments. Similarly, Warehouse Management Systems (WMS) manage information concerning the status of shipments inside the cross-dock. Web-portals automate the process of customer order entry into the TMS; whereas barcode systems automate the information management related to receiving goods. Another group of IT applications support operational decision-making. Route-planning tools support the planners in constructing transportation routes and evaluating alternative routing and consolidation decisions. Fleet telematics systems, consisting of on-board computers and an interface at the planning department, allow communication between the truck drivers and planners and inform the planners about the real-time status of the routes. A geo-fence tool combines functionalities of route-planning tools and fleet telematics systems to automate the assignment of trailers to docks at the cross-dock. Generally, the interviewees agree that the operational planning and control decisions regarding the focal carrier's C&D routes are well-supported by the available IT applications.

Table 2.3: IT applications in collaborative transportation networks

Case	TMS	WMS	Web-portal	Barcode system	Route-planning tool	Fleet telematics system	Geo-fence	EDI	XML
1	*v*	*v*	*v*	*v*	*v*	*v*			*v*
2	*v*		*v*	*v*	*v*	*v*	*v*	*v*	
3	*v*				*v*	*v*			*v*
4	*v*		*v*		*v*	*v*		*v*	
5	*v*	*v*		*v*	*v*	*v*		*v*	
6	*v*		*v*		*v*	*v*		*v*	
7	*v*				*v*	*v*		*v*	

In addition to the above IT applications, each case has IT applications installed to support collaborative transportation. These applications are all based on XML or EDI technology (see Table 2.3) and automate inter-organizational communication with long-term partner carriers. Despite the availability of local and inter-organizational applications, most interviewees pointed to a lack of visibility with regard to managing collaborative transportation and stressed the negative impact on operational performance. While a focal carrier is able to plan and control the operations of its single-party shipments, it lacks information about the operational planning and control of the part of transportation performed by its partner carriers.

In sum, the carriers in our case study rely upon partners for the execution of a considerable part of their transportation services. Nonetheless, our case results indicate that carriers do not jointly plan and control collaborative transportation at an operational decision-making level. Moreover, the broadly available IT applications do not support carriers in those joint decision-making processes. In order to gain understanding about the above findings, Section 2.5 and 2.6 discuss the results of two in-depth case studies focused particularly at the integration of different IT applications and joint operational planning and control between autonomous carriers.

2.5 Explanatory case findings

Below, we describe for each explanatory case the structure of the collaborative transportation network, the range of available IT applications, the operational planning and control procedures, and the issues with joint operational decision-making.

2.5.1 Case 1

Case 1 addresses a logistics service provider comprising seven autonomously managed business units. Each business unit operates a logistics facility in The Netherlands and specializes in certain logistics services. They collaborate to gain access to each other's resources and specialized know-how. The focus in *Case 1* is on the two business units that are responsible for transportation in The Netherlands, Belgium, and Luxembourg. Both receive requests for transportation from their customers, as well as from the other five business units, and handle those requests at their local planning departments. Each business unit operates a cross-dock for the consolidation of shipments. They engage in horizontal collaboration to concentrate the collection and delivery locations in the areas served from each cross-dock. Due to an overlap in the geographical areas that can be reached efficiently from the cross-docks, an important collaborative decision is concerned with determining which business unit should collect or deliver which shipment. A line-haul route is operated to facilitate the exchange of shipments between the two cross-docks. The line-haul route has a fixed time table and a capacity of 2 truckloads each way.

The IT infrastructure consists of IT applications supporting the planning department at each business unit and an XML-based middleware application to facilitate the information exchange between them. Although both business units acquired their IT applications from different vendors, each planning department has a similar set of applications for the support of operational planning and control—consisting of a TMS, a route-planning tool and a fleet telematics system. The XML-based middleware application is developed specifically to automate communication between the two planning departments and facilitates information exchange from one TMS to the other.

Planners from both planning departments use the IT infrastructure for the operational planning and control of local and collaborative transportation. At each department, the planners start their shift with assessing the overall planning problem from a local perspective and determining which collected shipments qualify for delivery by the other business unit. Shipments are allocated to the line-haul route and assembled into consolidated truckloads. The corresponding information is entered into the TMS when the exchange decision is finalized and then transferred to the other planning department by means of the middleware application. When the line-haul decisions are communicated, each planning department starts developing its C&D routes by means of the route-planning tool, which uses the updated data according to the exchange of shipments. Routes are finalized by allocating a resource combination (i.e., a truck, trailer, and driver) in the route-planning tool. To that end, the planners consider the availability of resource combinations based on the information from the fleet telematics system.

With regard to joint operational planning and control of collaborative transportation, two key issues emerged from *Case 1*. Firstly, the line-haul route has a fixed capacity; whereas the exchange of shipments under a dynamic line-haul capacity would be more efficient. We refer the reader to Chapter 3 and Lopez (2013) for in-depth studies to this particular issue. Secondly, the business units make exchange decisions from a local perspective, which confirms the exploratory case findings.

2.5.2 Case 2

Case 2 addresses a collaborative transportation network in the United Kingdom, which is structured as a hub-and-spokes system. The case company owns and operates the hub, whereas the C&D routes are planned and operated by around 150 autonomous small and medium-sized carriers—called *member depots*. Shipment redirected to the hub are collected by one of the depots (in this role referred to as a *collecting depot*), transported by the collecting depot to the hub by means of a line-haul route, and transshipped at the hub onto a line-haul route to the depot that will deliver the shipment (in this role the depot is referred to as a *delivering depot*). Each member depot fulfills both roles. The case company facilitates and coordinates the horizontal collaboration among its member depots by means of a few simple mid-term agreements. Chiefly, each depot is assigned to an exclusive delivery area. By affiliating with the hub, a depot commits to collecting shipments bound to its delivery area at the hub each night. The corresponding depot-hub transportation is operated as a line-haul route with flexible capacity, but according to a fixed time-table. Since most depots also operate private transportation routes and participate in other partnerships, an important collaborative decision at the depots is concerned with determining which shipments are sent through the collaborative network and which are fulfilled by other means.

An IT infrastructure is in place with the same TMS application installed at all depots. The IT infrastructure is developed, supported, and maintained in-house by the IT department of the case company. The status of each shipment in the TMS is updated at five pre-defined operational transactions: a collecting depot records a shipment upon customer order entry; a depot manifests a shipment for line-haul to the hub; a shipment arrives at the hub; a shipment departs from the hub; a delivery depot uploads a proof of delivery. The operational transactions at the hub and depots are recorded by means of an automatic barcode scanning system. The IT infrastructure connects the member depots' TMS applications by means of automated information transfers. Besides the TMS applications, the set of available IT applications differs strongly from depot to depot—and depots cannot access information from each other's systems.

The IT infrastructure is used by the member depots for communicating operational decisions about collaborative transportation. A depot can decide autonomously if a collected shipment is transported to the hub for delivery by another depot or transported without using the collaborative network—either by self-owned resources or via another partner. When these planning decisions are made, the corresponding line-haul trailers are loaded and the status of the loaded shipments is updated in the TMS. From that moment, the related delivering depots and the hub know about these shipments and plan their operations accordingly.

Two key issues in joint operational planning and control of collaborative transportation emerge from *Case 2*. The first issue appears in depot-depot relations, where delivering depots know only for certain that a shipment has to be collected from the hub when it is manifested by the collecting depot, i.e., when the collecting depot has effectuated its decision to send that shipment through the collaborative network. Since collecting depots postpone this decision as long as possible to optimize local resource utilization, a delivering depot receives information about its next day's planning problem at the last moment. Consequently delivering depots have difficulty in determining the required fleet capacity. The second issue appears in depot-hub and hub-depot relations, where detailed, and often dynamic, operational preferences of one party are not known to another.

2.6 Reflection based on typology

Based on a cross-case analysis of the case results, this section presents an explanation for the lack of joint operational planning and control in collaborative transportation networks—despite the broad availability of IT. To that end, we first propose a simple typology for IT applications.

2.6.1 Typology of IT applications

The below typology builds upon technological characteristics well-known in IT research, and hence is not claimed to be very innovative. Rather, our claim is that introducing this technology-oriented typology can contribute to supply chain literature as technological details of IT applications offer an explanation for the challenges associated with joint operational planning and control in collaborative transportation networks. At an operational level, the typology distinguishes the following types of applications based on their inherent technological differences[2]:

- Transaction Processing Systems (TPS), e.g., TMS applications.
- Decision Support Systems (DSS), e.g., route-planning applications.
- Real-time Systems (RTS), e.g., fleet telematics system applications.

Each type will be described in terms of its functionality, type of data, storage, and rendering of data. A summary of these characteristics is presented in Table 2.4.

Real-time systems (RTS) monitor certain physical variables—usually by means of sensor technology providing streaming data. Generally, these streaming data can be of any type, e.g., audio, video, text, and numbers. In the setting of this study, streaming data consist primarily of coordinates from the GPS sensors in on-board computers. RTS are almost continuously producing data, which are kept in log files. Sensor data may also be plotted in graphs or maps (e.g., showing trucks as they progress on their routes) or produce alerts when the sensor data are outside a predefined range.

Transaction processing systems (TPS) record changes in the status of relevant objects. TPS do not track sensor data. Rather, the status of objects is updated if a particular event occurs that is relevant from a business perspective, such as arriving at a destination, loading or unloading at intermediate logistics facilities, changes in orders or contracts. TPS use structured data, which is stored in databases. Generally, the related data is rendered visually as tables or as forms to be filled. TPS data is often entered manually, although data may also be retrieved from other TPS via EDI or XML-based connections. Occasionally, TPS receive data from RTS, but as we will describe later, this route is cumbersome.

Decision support systems (DSS) provide information deemed relevant for particular decision-making. At an operational planning level, a DSS often suggests decisions or computes the consequences of decisions considered by planners and managers, i.e., by means of what-if analysis. The data required for these computations mainly comes from TPS and is sometimes completed with some manual input, e.g., by defining

---

[2] *Wortmann et al. (2013) present a similar typology, which also includes IT applications at the tactical and strategic decision-making level, e.g., data warehousing applications.*

scenarios for what-if analyses. During computational analyses, structured data are typically stored in a non-persistent way, in fast memory (RAM), which enables prompt availability of DSS information.

Table 2.4: Characteristics of IT types

IT type	Function	Data types	Data source	Storage	Rendering
RTS	Monitoring	Various forms of streaming data	Sensors	Log files	Graphs; Maps; Alerts
TPS	Record object states	Structured data	Manual; other TPS (via EDI/XML); RTS	Databases	Tables; Forms
DSS	Provide decision support	Structured data	TPS; Manual	Non-persistent (RAM)	Tables; Graphics

The inherent technological differences between the three IT application types described above (TPS, DSS, and RTS) often hinder the integration of applications from different types. Below we discuss the key integration issues based on six interfaces (see Figure 2.2).

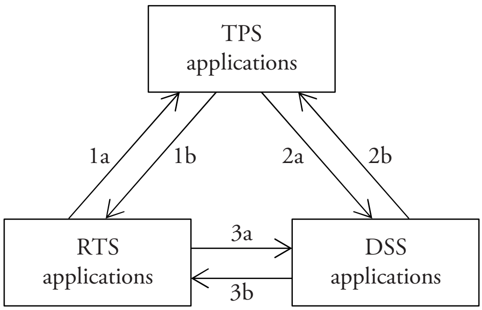

Figure 2.2: Interfaces between different IT application types

1a – Updating TPS with RTS data: Automatically updating the status of an object in a TPS necessitates a clear set of conditions (i.e., specifying exactly when that status should change) and dedicated software. A geo-fence application, as encountered in one of the exploratory cases, is a good example. In practice, however, a clear set of conditions is often lacking. Consider, for example, the situation when a truck has been situated at a delivery location for 15 minutes. What does this mean regarding the status of that delivery in the TPS? Is the delivery nearly completed? Is the truck still waiting? Will the delivery be delayed? Hence, the meaning of the RTS data is important to determine the status of an object—and is easier interpreted and updated in the TPS manually.

2a – Uploading data from TPS to DSS: Provided that the data models of the TPS and DSS are identical, interface *2a* is easily established by taking a snapshot of the TPS data and transferring it to the DSS. Notice that the TPS should not "move" during the snapshot, i.e., transactions posted to the TPS should be put on hold for a short period of time.

3a – Using RTS data in DSS: RTS data is often visualized to the decision-maker. Sometimes that visualization is merged with the DSS data display. Nevertheless, actually using RTS data in DSS applications is cumbersome. Typical planning and control algorithms—as embedded in contemporary DSS—cannot handle the large stream of continuously changing RTS data. Accordingly, RTS and DSS applications are rarely integrated.

3b – Updating RTS with DSS data: RTS applications require information about planning decisions from DSS in order to monitor ongoing operations with respect to those planning decisions. Typically, the related information is transferred via a TPS application, i.e., through interfaces *2b* and *1b*. Accordingly, interface *3b* is not included in our discussion.

2b – Updating TPS with DSS data: After planning and control decisions are formalized in DSS, the states of related objects should be updated in the TPS. The main challenge with downloading DSS data into TPS is that, by the time a decision is formalized, reality as reflected in the TPS data may have changed.

1b – Downloading data from TPS to RTS: Formalized DSS decisions are forwarded to a RTS application via a TPS application. In a transportation setting, these data consist of shipping lists and route plans for trucks. Due to the clear information exchange requirements, interface *1b* is established relatively easily.

It follows from the above discussion that the key integrating issues reside in updating a TPS with detailed and continuously changing DSS and RTS information. Accordingly, a typical TPS application does not fully reflect the real-time situation nor does it show the intended decisions and scenarios considered by the decision-makers.

2.6.2 Case reflection

The proposed typology and identified IT integration issues provide a clear explanation for the apparent lack of joint operational planning and control in our cases. First of all, it should be noticed that the three information systems application types can be recognized in the participating cases, i.e., all cases use a transport management system (TPS), a route-planning tool (DSS) and they communicate plans and exceptions with their drivers by means of a fleet telematics system (RTS).

Regarding the IT infrastructures encountered in the two explanatory cases, we highlight the following observations. Firstly, the internal integration of different IT application types (i.e., within each decision-making unit) reflects the general integration issues described above. Therefore, the real-time situation (captured by RTS) and the preliminary decisions (considered using DSS) are not reflected in the TPS applications. Secondly, external IT integration consists of connections between the local decision-making units' transport management systems. Although the connections differ in level of sophistication, from manually created XML messages to a dedicated middleware application enabling fully automated information exchange, all are similar in the sense of the IT application type they connect, i.e., TPS only. In retrospect, the same observations regarding external IT integration apply to the exploratory cases. The different forms of IT integration are displayed in Figure 2.3, where the dotted lines indicate connected, yet not fully integrated, applications.

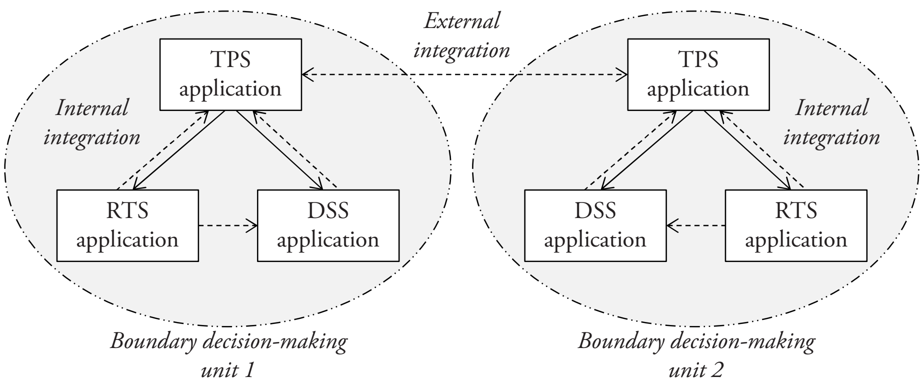

Figure 2.3: IT integration based on typology

The above reflection suggests that the well-known inter-organizational IT integration based on XML or EDI connections—as often discussed in supply chain literature—

is, in fact, only a connection between the TPS applications of different decision-making units. Our cases show that the resulting information exchange between peer-planning groups does not enable joint operational planning and control of collaborative transportation. The connection between TPS applications of multiple autonomous decision-making units facilitates the exchange of *ex-post* information about local operational planning and control decisions. While valuable in itself, such information exchange does not support a planner in decomposing and integrating different planning domains. That is, a planner is not aware of how its local planning domain fits the collaborative transportation network's overall planning domain. Similarly, a planner is not supported in deciding which part of the local planning domain should be considered jointly with a planner from a partner carrier. Planners may share documents on dedicated spaces on the internet, but this is not the same as joint optimization. The lack thereof—as a result of the IT integration issues specified in our typology—explains why joint operational planning and control is hardly encountered in collaborative transportation networks.

Some additional remarks may be worthwhile here. Our case findings indicate that current IT development efforts are aimed at further improving the existing TPS-TPS application connections. The focus on TPS-level IT integration can be explained by the relative mature status of the EDI and XML technologies used to implement such integration. However, it should be noticed that these technologies are developed to exchange structured data. As a consequence, it is far from trivial to exchange RTS data with other parties by means of these technologies. The typical heterogeneousness of real-time data across different decision-making units necessitates novel and highly sophisticated data standardization solutions (e.g., Van Blommenstein, 2013). Furthermore, exchanging DSS information between multiple autonomous parties by means of the typical TPS connections is prone to the above discussed IT integration issues. For example, how can it be guaranteed that the snapshot of multiple TPS applications is taken at the same time?

In the light of the above remarks, any expectations with regard to XML and EDI-based IT integration for improving joint operational planning and control should be considered with care. Rather than a focus on further improving the use of EDI and XML technology alone, the case study results in this chapter may encourage scholars and practitioners to develop new procedures and dedicated IT applications for joint operational planning and control in collaborative transportation networks. For example, the current state of external integration, as shown in Figure 2.3, suggests a need for IT applications facilitating direct connections between DSS application at among autonomous decision-making units; or likewise among RTS applications. Given the technological characteristics of these types of applications, the development and use of such software are promising areas for future research.

2.7 Conclusions

This chapter addresses horizontal collaboration among autonomous freight carriers and explains the role of IT therein. It complements prior empirical studies on strategic and tactical aspects of horizontal carrier collaboration by providing a detailed conceptualization of joint operational decision-making among collaborating carriers. Our study indicates that carriers strongly rely on horizontal collaboration in the execution of their transportation services. Nonetheless, they face fundamental challenges when it comes to joint operational planning and control of collaborative transportation—despite the broad availability of state-of-the-art IT. In this chapter, we propose an IT typology that explains those challenges.

The typology proposed in this chapter considers detailed technological characteristics to distinguish among different IT application types. This is in sharp contrast with existing supply chain literature, where IT is often considered in abstract terms or only a single IT application is addressed. By considering the technological characteristics of IT in detail, we reveal persistent integration issues between the different types of IT applications. This chapter shows that those IT integration issues result in a lack of joint operational decision-making. One important implication of our study is that the commonly held perception that state-of-the-art inter-organizational IT applications facilitate supply chain collaboration does not stand up to empirical scrutiny when it comes to joint operational planning and control.

Chapter 3.

Intensifying horizontal collaboration to improve transport efficiency at a Dutch logistics service provider

3.1 Introduction

This chapter studies the collaboration between two business units of the Dutch logistics service provider *Fritom* and proposes alternatives to further improve their collaborative transport planning. Fritom consists of seven autonomous business units providing a range of logistics solutions, such as warehousing, value added logistics, liquid food logistics, freight forwarding, and freight transportation. Their combined annual turnover is around €150M. A considerable part of Fritom's business concerns the domestic transportation of less-than-truckload shipments, which is fulfilled by two business units that, until recently, were independently owned freight carriers. To date, the two business units house their own autonomous planning and customer relations department, which receive and handle requests for transportation. The network configuration of each business unit consists of a single depot from which pickup and delivery locations spread across The Netherlands are serviced. One business unit operates a depot that is situated in the North of The Netherlands; the other in the South.

Recently, the two business units started to collaborate in providing the domestic freight transportation services. As a result of their collaboration, a new *joint* network configuration emerged. The joint network consists of two depots that serve as a home base for trucks and can both be used for transporting loads from pickup to delivery locations. In this chapter, we show how the combination of such individual network configurations leads to a new type of vehicle routing problems that has not been addressed in the literature. The main modelling challenges for this new type of problems reside in determining how loads are best routed through the joint network, i.e., directly or via one or multiple depots. Furthermore, we extensively study the situation at Fritom, provide alternatives for their collaborative transport planning approach, and present evaluate those alternatives based on a large data set comprising a full year of Fritom's operational data.

3.2 Background

This background section consists of a practical and a theoretical part. In the practical part, we describe Fritom's current organization and planning processes for domestic freight transportation. In the theoretical part, the route planning problems faced by Fritom are related to existing Operations Research literature.

3.2.1 Practical background

Fritom's domestic freight transportation activities are fulfilled by two of its business units: *Veenstra|Fritom* (V|F) and *Sanders|Fritom* (S|F). V|F operates a depot in the North of The Netherlands; S|F in the South. In principle, an unlimited fleet of trucks is available at the depots as additional resources can be chartered when needed. Each business unit houses an autonomous planning department, which processes transportation requests throughout the day from a large number of customers and from Fritom's other business units. An analysis of transactional data from 2012 reveals that S|F received about 500 requests each day; V|F 300. The requests strongly vary with regard to load-size, time restrictions and locations of pickup and delivery jobs. The majority of requests specify a very small load (the average load-size is less than three Euro-pallets) with loose time restrictions for visiting the pickup and delivery locations (e.g., the pickup of a load can occur between 8AM and 5PM at day 1 and its delivery between 9AM and 6PM at day 2). Due to the traditionally regional contacts of the business units, the pickup locations of most loads are nearby the depot of the business unit that receives the requests. Delivery locations are geographically dispersed across the country. The average distance between a pickup and delivery location is about 100 kilometers. A single request can specify multiple pickups and/or deliveries.

Fritom has several options to fulfill a request. That is, a load can be transported from its pickup to its delivery location without an intermediate stop at a depot or can be redirected to a depot. At Fritom, most loads are redirected to a depot, where they usually stay overnight. A redirected load typically arrives at the depot in the late-afternoon, where it is moved into a truck that departs from that depot early the next morning. There are three main reasons for this being the default fulfilment option. Firstly, it yields more opportunities for consolidation and the planners can identify those opportunities more easily. Due to the many small-sized loads, consolidation is imperative for sustainable and cost-effective transportation. Secondly, when redirecting most loads to a depot, it is easier to dynamically insert loads from new requests into on-going transportation routes. Consequently, Fritom can accept virtually all requests while upholding a high service level. Thirdly, the time restrictions for most requests simply allows for redirection with an overnight stay at the depot, i.e., 97% in 2012. Indeed, 29% of the requests in 2012 even required an overnight stay. An example of the latter type of requests is a load with a single pickup job and multiple, geographically dispersed delivery jobs that cannot be fulfilled within the specified time restrictions by a single truck. Whereas redirecting loads to the depot is the default fulfilment option, 3% of Fritom's requests in 2012 required transporting a load from its pickup to its delivery location without an overnight stay at the depot (e.g., due to short time span between pickup and delivery).

The problem of planning Fritom's domestic transportation entails the construction of routes to pick up and deliver loads as specified in the received requests. The objective is to minimize the overall transportation costs, for which the total travel distance is a key driver. Currently, the focus at both planning departments is on constructing vehicle routes to fulfil the requests received by their own business unit. Accordingly, we first describe Fritom's planning problem as encountered by each business unit individually. These problems are similar for V|F and S|F.

Since requests are received throughout the day, the *degree of dynamism* (Larsen *et al.*, 2002; Pillac *et al.*, 2013) of Fritom's planning problem depends on the service promised to its customers, the chosen planning horizon and the moment at which planning decisions are made. Fritom's service promise for domestic transportation dictates that the fulfilment of a request arriving before 1PM today will be completed tomorrow at the latest. The planning horizon encompasses a full day of operations, i.e., from the moment the first truck departs the depot (typically around 6AM) until the last truck has returned (typically around 7PM). At both V|F and S|F, route planning decisions are made in two shifts: a day and an evening shift. In the evening shift, one or two planners construct routes to fulfil a set of requests that have to (or can) be fulfilled the next day. As no new requests arrive during this planning shift, it concerns a static planning procedure. The vast majority of the considered requests specify deliveries of loads that have already been picked up and are located at the depot. In the day shift, a group of two or three planners construct new routes to fulfil newly arriving requests. Moreover, loads can be dynamically inserted into existing (and on-going) routes. Requests that are inserted into (new) routes typically specify a load that can either be picked up the same day or the next day and have a delivery deadline the next day. Requests that are not addressed during the day shift are addressed in the subsequent evening shift.

Fritom's planners are supported by a transportation management system. Nonetheless, the actual construction of routes is performed manually. A typical route departs from a depot carrying loads to be delivered and returns to the same depot with loads that were picked up for delivery the next day. The planners also have to address the requests that do not allow for an overnight stay at the depot. Moreover, they seek for opportunities to reduce transportation costs by directly transporting loads that do allow for an overnight stay. Three types of routes exist that directly transport loads from pickup to delivery location. First, a single request can be fulfilled by means of a dedicated truck. Second, a single truck can fulfil the pickup and delivery for a set of requests. Third, a load can be picked up and delivered by a single truck that also carries loads that are to be transshipped overnight at the depot. Hence, the planners can fulfil requests by means of many types of vehicle routes. Fritom considers this flexibility in routing to provide a strong competitive advantage as it results in low transportation costs and high service levels.

In recent years, V|F and S|F successfully deployed a collaborative structure to improve sustainability and reduce transportation costs. During the day shift, planners at each business unit decide for arriving requests whether the pickup, or pickup *and* delivery, can be better executed by the other business unit. Opportunities in that regard are identified manually and ad-hoc. Most collaborative efforts take place during the evening shift, however, when opportunities are sought to exchange delivery loads that were redirected to a depot. Specifically, the planners consider which of the loads that are (or will soon arrive) at their depot can better be delivered by the other business unit. These loads are then transferred between the two depots by means of a shuttle connection.

Currently, the exchange of delivery loads is structured according to the following decision rules. The shuttle connection has a fixed daily capacity of two truckloads with pre-set departure times in the evening so that the transferred loads can be incorporated in the next day's vehicle routes departing from the other depot. Each business unit decides autonomously which of their delivery loads are to be fulfilled by the other business unit. Planners in the North start considering loads with the most Southern delivery location—working their way up until both shuttle trailers are fully loaded. Planners in the South start considering loads with the most Northern delivery location. Whether a load is allocated to a shuttle trailer is determined manually and from a unilateral perspective. Accordingly, loads that can be delivered cost-effectively from their own depot are often not transferred—even when a transfer might have contributed to Fritom's overall domestic transportation performance.

3.2.2 Theoretical background

The route planning problem underlying Fritom's domestic transportation services is related to the domain of pickup and delivery problems. A vast body of Operations Research literature describes variants of the pickup and delivery problem and proposes solution approaches. An early overview of existing literature in that domain is presented in Savelsbergh and Sol (1995). Berbeglia *et al.* (2007) and Parragh *et al.* (2006, 2008) each propose a slightly different scheme to classify pickup and delivery problems in two unique problem classes: the *pickup and delivery problem* (PDP) and the *vehicle routing problem with backhauls* (VRPB).

In the PDP, routes are to be constructed for a fleet of vehicles such that loads are transported from their origin to their destination in a single vehicle route, i.e., without visiting a depot in between (Savelsbergh and Sol, 1995). The VRPB is a special case of the PDP where either the origin or the destination of each load is at the depot (Goetschalckx and Jacobs-Blecha, 1989). Accordingly, vehicles depart from the depot carrying all loads to be delivered and arrive at the depot carrying all loads picked up at the customer locations. Variants of the VRPB (i) enforce routes to finish all deliveries before starting with the first pickup, (ii) allow routes to deliver and pickup loads in any sequence, or (iii) consider customer locations that simultaneously receive and send loads (Nagy and Salhi, 2005). Heuristics for solving variants of the PDP and VRPB considering single and multiple depots exist in the literature. Ropke and Pisinger (2006a), for example, propose a heuristic for solving a PDP with multiple depots. Nagy and Salhi (2005) and Nagy *et al.* (2013) propose a heuristic for the VRPB that can solve problems with single and multiple depots.

The PDP and VRPB each resemble a part of Fritom's routing problem as described in the *practical background*. Those requests for which the pickup and delivery location have to be visited in a single vehicle's route fit the PDP. Requests that must be redirected to the depot can be modelled by means of two VRPB requests in different planning periods. In the first planning period, a route picks the load at its origin and carries it to the depot. In a later planning period, another route starts at the depot and carries the load to its destination. The VRPB is based on the simplifying assumption that each load is available at the depot from which its delivery vehicle departs (Ropke and Pisinger, 2006b). In practical settings with multiple depots, however, a planner can choose a depot for transshipment of a load, after which the load must be delivered from that specific depot.

Note that the PDP assumes that a vehicle cannot visit a depot while carrying loads. Accordingly, requests that *must* be redirected to a depot cannot be considered in the PDP. By contrast, the VRPB assumes that all loads for delivery are located at the depot and that all loads for pickup are destined for the depot. Requests that *cannot* be redirected to a depot cannot be considered in the VRPB. Furthermore, requests can have a fulfilment choice, i.e., they allow for redirecting a load to the depot, but could also be fulfilled in a single route. At Fritom, the percentage of requests with a fulfilment choice is high (68% in 2012). The routes for fulfilling those requests could be constructed by modelling the problem as either a VRPB or a PDP. If modelled as a PDP, the potential benefits from redirecting a load to a depot are lost. Modelling the problem as a VRPB may result in lost opportunities that emerge from fulfilling a load's pickup and delivery in a single route. Thus, in order to find the best routes for requests with a fulfilment choice, the decision whether or not to redirect a load to one or multiple depots should be part of the model.

A sub-class of the PDP allows loads to be transferred between multiple vehicles and is referred to as the PDP with transfers (PDPT). Different from the situation described in the *practical background*, transfers in the PDPT can only occur when the requests are fully serviced within a single planning period. Moreover, existing PDPT solution methods can only solve small problem instances. Mitrović-Minić and Laporte (2006) assess the benefit of allowing transfers and propose a heuristic that solves instances of 50 and 100 requests with 4 transfer points at most. Cortés *et al.* (2010) propose a branch-and-cut algorithm to solve instances up to 6 requests, 2 vehicles and 1 transfer point to optimality. Rais *et al.* (2014) present mixed integer-programming formulations for the PDPT with and without time windows and solve instances of 5 and 7 requests and as many vehicles to optimality. In these instances, transshipment is allowed at all nodes in the network. Solution approaches for larger instances do exist for the dial-a-ride problem (DARP), which considers the transportation of persons instead of goods. Masson *et al.* (2013) propose a heuristic for instances up to 193 requests. These instances include a very small number of delivery locations compared to the number of pickup locations. In general, the DARP puts emphasis on the quality of the transport service provided, particularly with regard to the service time and maximum number of transfers. Therefore, the time windows are very strict, which considerably reduces the possibilities for transfers.

In summary, existing literature has addressed only aspects of the routing problems typically faced by collaborating freight carriers, such as Fritom. A formal definition addressing the full extent of this class of practical problems has not yet been formulated in the literature, nor have solution approaches been proposed. Therefore, in the subsequent section, we first present a definition of a new, wider class of pickup and delivery problems.

3.3 Defining the Generalized Pickup and Delivery Problem

In this section, we present a definition for a new class of vehicle routing problems. This definition is inspired by real-world routing problems as faced by collaborating road-freight carriers in the LTL industry—and by Fritom in particular. We refer to this class as the *generalized pickup and delivery problem* (GPDP), which is an even further generalization of the general pickup and delivery problem proposed in Savelsbergh and Sol (1995). In particular, our definition relaxes the constraints that a load has to be transported within a single planning period and by means of one vehicle from its origin to its destination.

In the GPDP, vehicle routes have to be constructed to satisfy a set of transportation requests subject to an objective, such as minimizing the total travel distance. A transportation request specifies for each load its size, its origin, its destination and time windows for visiting the origin and destination. There are multiple depots, each with a fleet of vehicles to operate the routes. Each vehicle has a given capacity, which may differ among vehicles. A vehicle starts and ends its route at a specified depot and visits a number of locations to pick up and deliver loads. During a route, the vehicle is allowed to visit one or multiple depots for the transshipment of loads, i.e., drop off loads for pickup by other vehicles or pick up loads that were dropped off by other vehicles. As long as the time windows are satisfied, the pickup of a load is allowed to be performed in another planning period than its delivery. Therefore, a vehicle can end its route by dropping off loads at the depot for final delivery in a future planning period. Similarly, a vehicle route can start at the depot by picking up loads that were dropped off in a previous planning period.

The above problem implies the following fulfilment decisions for each request. A load can be transported by means of a single route or by means of multiple routes (and potentially multiple vehicles). In the case a load is to be transported from its origin to its destination through multiple routes, it must be decided to which and how many depots the load is redirected. Moreover, a decision must be made regarding the planning period in which parts of the transportation is performed. By considering multiple periods, the GPDP takes into account to which depot the loads are best directed. We note that the characteristics of a particular request (e.g., time windows) can result in multiple feasible fulfilment options.

3.4 Proposed alternative collaborative configurations

The sustainability and cost-effectiveness of Fritom's domestic transportation has considerably improved as a result of the recent collaboration between the two business units. Based on their positive experience with collaboration thus far, Fritom's managers expect additional improvements from further developing their collaborative structure. They seek quantitative evidence supporting this expectation and anticipate innovative tools to be required to successfully expand their collaborative efforts. This business objective formed the starting point of our research. In this section, we propose and evaluate two alternative configurations for Fritom's current collaboration and discuss the existing solution approaches from literature on which our alternatives are inspired. We acknowledge that the proposed alternatives will not yield an optimal, or near-optimal, solution to the GPDP. Rather, the aim is to take a next step towards solving the joint routing problem that emerges when the individual routing problems of V|F and S|F would be fully integrated—and as such forms an illustrative example of the GPDP.

An optimal solution to the joint routing problem of V|F and S|F would implicitly allocate the fulfilment of requests to depots. As explained in the *theoretical background*, this problem does not match any existing formulation in the literature and designing a solution approach entails tackling several new modelling challenges. Finding a good solution for the routing problem of each business unit separately is less complex. Accordingly, several methods have been proposed in literature on related problems that first allocate requests to depots and then solve a standard vehicle routing problems for each depot separately (e.g., Wasner and Zäpfel, 2004). These methods rely upon the premise that determining a good request allocation is a feasible step towards finding a reasonable solution to the underlying joint routing problem. The two alternative collaborative configurations proposed below follow this line of reasoning.

3.4.1 Proposed alternatives

The scope of the alternatives we propose is limited to the exchange of delivery loads that are redirected to a depot. Our reasons for adopting this particular scope are threefold. Firstly, the vast majority of loads is currently redirected to a depot. Therefore, most loads are considered for collaboration in the proposed alternatives.

Moreover, the adopted scope does not impede the identification of opportunities for collaboration for loads that are not redirected to a depot. Secondly, according to Fritom's current organizational structure and procedures, the construction of vehicle routes for delivering loads is static and deterministic. Therefore, the data of all considered requests is available at the moment the collaborative decisions are made. Thirdly, the scope is compatible with the current modus operandi for collaboration. Overall, the adopted scope increases the likeliness that the proposed alternatives will actually be implemented in practice, which is an important objective of this research.

Configuration 1: Fixed geographical division

Configuration 1 divides The Netherlands into two parts, where V|F and S|F only deliver loads in their respective part of the country. To this end, two-digit postcode areas for delivery (*delivery areas*) are allocated to the depot of either V|F or S|F for a long period of time, e.g., one year. A long-term allocation of geographical areas to depots is common in transportation network design literature, where each depot in the network is often made responsible for all fine-grained transportation activities within its fixed geographical area (Crainic, 2000). Our inspiration for Configuration 1 stems from existing solution approaches for the design and control of hub-and-spoke networks (e.g., Wasner and Zäpfel, 2004; Zäpfel and Wasner, 2002).

Configuration 1 first allocates delivery areas to V|F and S|F and then solves the resulting routing problems for the deliveries from each depot separately. We adopted a distance-based delivery area allocation as initial solution. That is, each delivery area was allocated to a depot by finding the minimum of the distances between the centroid of that delivery area and each depot. The initial solution was improved by quasi randomly re-allocating (groups of) delivery areas around the geographical division, i.e., in the middle of The Netherlands. We evaluated the impact of each re-allocation by simulating the total route length related to delivering loads over a full year of operations. This total route length consist of the length of the vehicle routes delivering loads from each depot and the kilometers driven by the shuttle trucks required to transfer loads between those depots. A load must be transferred between depots when a particular allocation of delivery areas specifies that the delivery of that load is to be fulfilled by another depot than the one that picked it up. Similar to the real-world situation at Fritom, a shuttle trailer always makes a round-trip between depots. The length of V|F's and S|F's delivery routes is simulated by constructing vehicle routes using a modified version of the nearest neighbor heuristic. Our version of this well-known heuristic includes parameters that specify the capacity of the vehicles; the speed of the vehicles; the stopping time at pickup and delivery locations; and the maximum driving time. In our discussion of the *experimental results* below, the allocation with the lowest total route length was selected as the representative for this configuration.

Configuration 2: Variable geographical division

Configuration 2 re-allocates individual delivery loads between V|F and S|F considering daily route efficiency. The corresponding geographical division can vary from day to day. Moreover, in contrast to Configuration 1, this configuration allows delivery areas to be visited by both depots. Configuration 2 is inspired on existing solution methods that re-allocate requests among autonomous freight carriers for the purpose of improving their overall routing efficiency (e.g., Berger and Bierwirth, 2010; Wang and Kopfer, 2013). These methods allow each autonomous carrier to first decide which of its requests are offered to the collaborating partners. Subsequently, each carrier can place bids specifying, for example, its costs for fulfilling each combination of requests. A combinatorial auction is applied to find the best re-allocation of requests among the carriers. The design of these methods implies that planners at the carriers can give a good estimation of the operating costs for any possible combination of requests. Alternatively, Schwind *et al.* (2009) propose an auctioning architecture that automatically evaluates the operational gains associated with the re-allocation of each combination of requests based on the delivery routes of the individual carriers. In implementing that architecture, they noticed it is computationally intractable to evaluate every potential request re-allocation into all potential routes. Accordingly, they developed a simple distance-based measure to generate the input to the auction.

For the design of Configuration 2, we follow the logic of Schwind *et al.* (2009) regarding the automatic route-based evaluation of re-allocating requests, but consider batches of delivery requests as an alternative means to keep the problem computationally tractable. It extends the current collaborative configuration at Fritom. Currently, the planners identify loads that qualify for delivery by the other business unit manually, ad-hoc, and considering the potential benefits for their business unit alone. In the configuration we propose, this procedure is systematized. Furthermore, Configuration 2 allows for daily changes in shuttle capacity; whereas the current shuttle capacity between V|F and S|F is restricted to two truckloads.

In Configuration 2, delivery loads are re-allocated considering the day-to-day total route length. Loads are re-allocated to a shuttle trailer according to a prioritization list for each business unit. These lists are constructed by calculating for each load the difference between the distances from its destination to each depot. Hence, a load with a destination far from the depot of the business unit that received the request, but nearby the other depot, is re-allocated first. Starting with the initial request allocation (i.e., as received by each business unit), the volume of re-allocated loads is iteratively increased in batches of one full shuttle trailer. For each day, the total route length associated with delivering loads (i.e., V|F's and S|F's delivery route lengths and the shuttle route length) is calculated for zero to ten shuttle trailers—again using our nearest neighbor heuristic. In our discussion of the *experimental results* below, the number of shuttle trailers and corresponding re-allocation of requests with the lowest number of kilometers was selected as the representative for this configuration.

3.4.2 Experimental setting

We have developed an experimental setting, in which the above configurations can be compared by consistently simulating Fritom's operations. The experiments are conducted with one full year of operational data obtained from both business units, i.e., 2012. We merged the two data sets into a single data set that specifies for each request a unique identifier, the load-size, the delivery location, the delivery date, and the originating depot, i.e., the depot to which a load was actually redirected. We cleaned the data set by eliminating loads that were transported directly between their origin and destination. Requests with missing information were also deleted. Moreover, we translated the various measurement units for load-size in the original data sets into a single unit, i.e., for each request, the load-size is expressed in loading meters. Lastly, days at which the number of requests and load volumes for one or both business units are extremely high or low (e.g., due to holidays) are excluded using a range of 2 times the standard deviation from the mean. As a result, 220 out of 242 days of operations were part of our experimental analysis.

3.4.3 Experimental results

Table 3.1 shows the results of the experiments for each configuration. Specifically, it shows for each configuration the total length of delivery and shuttle trailer routes (expressed in km's) for the entire experiment, i.e., 220 days.

Table 3.1: An overview of the experimental results

	Initial request allocation – no collaboration	Configuration 1: Fixed geographical division	Configuration 2: Variable geographical division
Delivery routes (km)	4,826,058	3,087,941	3,237,147
Shuttles (km)	-	787,752	433,566
Overall km's	4,826,058	3,875,693	3,670,713

Table 3.2 displays the relative savings between configurations. It shows that the proposed collaborative configurations improve transport efficiency compared to the situation where vehicle routes are constructed for the initial request portfolios of V|F and S|F, i.e., with no collaboration. Moreover, we conducted a paired t-test to assess whether the differences were significant and calculated Pearson's *r* to determine the effect size.

Table 3.2: Relative savings between configurations

Compared configurations	Total km's saved	% total savings	Average km's saved per day	t-value	Df	Sig.	Effect size (r)
Configuration 1 vs. Initial request allocation	950,365	19.7	4,320	43.5	119	$p < .01$	0.95
Configuration 2 vs. Initial request allocation	1,155,345	23.9	5,252	55.3	119	$p < .01$	0.97
Configuration 2 vs. Configuration 1	204,980	5.3	932	30.3	119	$p < .01$	0.90

Table 3.1 shows that Configuration 1 considerably reduces the length of the delivery routes. Nonetheless, this configuration is not highly appropriate with regard to Fritom's request characteristics due to the inevitable inefficiencies associated with the transfer of loads between the fixed geographical areas. Many requests specify a load with an origin in the geographical area of one depot and a destination in the area of the other. Therefore, the number and volume of loads requiring a transfer is high. On average, 7.4 shuttle trailers are required to transfer loads from the South (i.e., the S|F depot) to the North (i.e., the V|F depot) and 6.4 trailers the other way around. The main shuttle trailer inefficiency resides in the imbalance between the volumes of

loads to be transferred. This imbalance causes empty hauling of shuttle trailers. On a yearly basis, there are 477 empty backhaul shuttle trips in Configuration 1. As a consequence, the delivery route costs savings are partly diminished by shuttle costs.

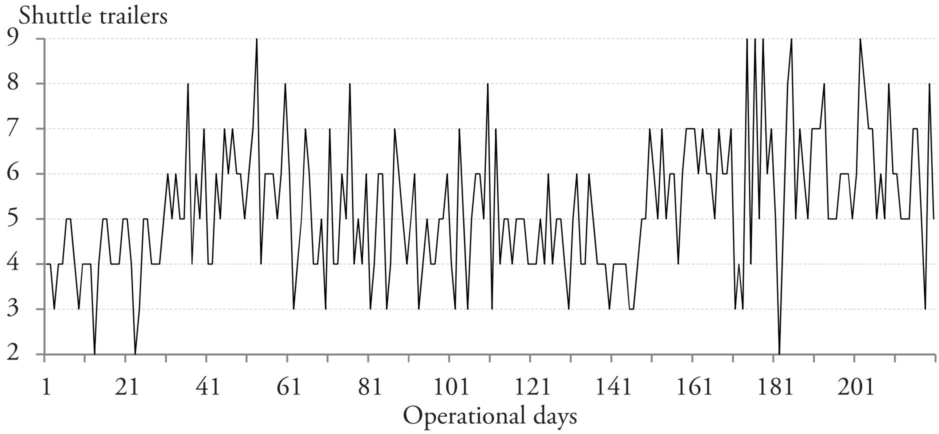

Figure 3.1: The varying number of shuttle trailers from day to day

Configuration 2 significantly outperforms Configuration 1 by 5.3% (i.e., 204,980 km). This configuration allows the number of shuttle trailers to vary from day to day in order to improve the overall routing efficiency. Figure 3.1 displays the corresponding number of fully loaded shuttle trailers for each considered operational day, which varies between 2 and 9.

We also investigated the degree of specialization associated with Configuration 2. Figures 3.2a and 3.2b highlight postcode areas if they were visited by only 1 business unit more than 98% of the days. In contrast to the fixed geographical division of Configuration 1, a considerable number of postcode areas are visited by trucks from both depots in Configuration 2. The fact that some delivery areas are visited by trucks from both depots in Configuration 2 leads to less efficient delivery routes compared to Configuration 1. Nonetheless, due to the more efficient utilization of shuttle trailer capacity, the overall savings are much higher.

Lastly, the performance of the current collaborative configuration at Fritom is estimated by running the experiment with 2 shuttle trailers under the method presented in Configuration 2. This experiment results in 3,928,908 kilometers in total, from which 166,320 stem from operating the shuttle trailers. Compared to our estimation of Fritom's current collaborative configuration, Configuration 1 improves the total route length by 1.4% (t (219) = 4, $p < .01$, r, 0.28); whereas Configuration 2 improves the total route length by 6.6% (t (219) = 25, $p < .01$, r, 0.86). We expect the actual savings to be even larger. This is due to our estimation of the current performance, which underestimates the total route length as it applies our structured approach for re-allocating requests; whereas the planners actually re-allocate requests ad hoc, manually, and based on a unilateral perspective. Nonetheless, our experimental results provide quantitative empirical evidence supporting the expectation that further developing Fritom's collaborative structure yields additional transport efficiency improvements. In that regard, Configuration 2 (i.e., with a variable geographical division—extending Fritom's current collaborative logic) considerably outperforms Configuration 1 (i.e., with a fixed geographical division—as often encountered in transportation network design literature).

Figure 3.2a: Configuration 1 – representative geographical division used in the experiments

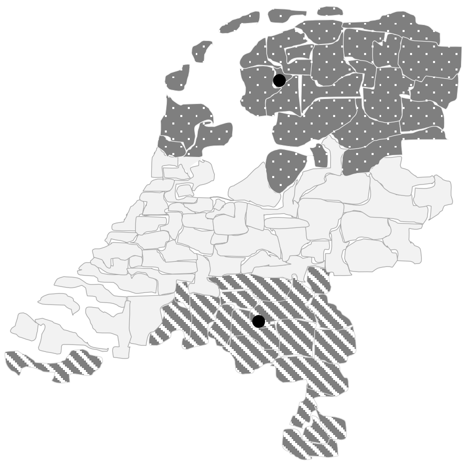

Figure 3.2b: Configuration 2 – postcode areas that are almost always visited by only one depot

3.5 Towards implementation

Intermediary and final results of the above experiments were frequently discussed with Fritom's management. During those meetings, the managers understood and confirmed the limitations of Configuration 1 associated with its inability to cope with the large imbalance in freight flows. More importantly, they corroborated the positive results and magnitude of the estimated improvements of Configuration 2. Fritom's management indicated that a cost of €1/km is a valid estimation for the actual transportation costs associated with delivering loads domestically—including fuel, labor and depreciation costs. Compared to their current collaborative configuration, the expected yearly cost saving of Configuration 2 is over €260,000. Fritom asked us to prepare for an actual implementation of this configuration. Accordingly, we developed an IT tool systematizing the transfer decisions according to in Configuration 2. Moreover, we made several multi-day visits to both business units to identify potential challenges related to the implementation and use of this tool. To complete the preparations for implementation, we formulated the following recommendations to Fritom's management:

Recommendation 1: At both planning departments, we observed that certain types of loads are not considered for a transfer even when their delivery area can be serviced more efficiently from the other depot. For example, the current policy dictates that loads bigger than 6 Euro-pallets are not transferred between depots. Moreover, the planners sometimes decide that they want to exert full control over the delivery of a particular load due to, e.g., a delivery area requiring a specialized driver, a tight delivery time window, or customer intimacy. In order to efficiently service these *exception loads*, many regular loads that could better be transferred end up in routes with an exception load. On the one hand, this enables the fulfilment of exception loads by means of routes with acceptable efficiency. On the other hand, even a few exception loads each day may have a high "collateral damage". Indeed, we observed that the planners sometimes have difficulty in identifying sufficient loads to fill two shuttle truckloads. Our experimental results show that the optimal number of shuttle trailers is five on average when no exceptions are considered. Consequently, we recommended to analyze the different types of exception loads and decide for each type the need to consider them as exceptional. Our proposed method can be used to calculate the exact transportation costs associated with each type of exception. Fritom's managers can use this insight and weigh the actual transportation costs against managerial reasons for considering particular exceptions.

Recommendation 2: The manual, ad-hoc, and unilateral transfer decisions in the current collaborative configuration leave many operational synergies unexploited. We observed that the planners at both business units use the possibility to transfer loads mostly for the elimination of those loads that cannot be delivered efficiently from their depot. Currently, the planners identify few loads that can be fulfilled more efficiently by means of a transfer if those loads can be fulfilled at an acceptable efficiency level from their own depot. We note that, up to a certain shuttle trailer capacity, for each load that is transferred to the other depot a "better" load is received, regardless of the unilateral efficiency associated with the exchanged loads. Without OR support it is difficult to identify which, and how many, loads are best transferred. The purpose of the IT tool we developed to implement Configuration 2 is to identify those aspects. We recommend using a tool that can systematize the transfer decisions at both business units.

Recommendation 3: Although not part of our initial setup, we did consider the impact of implementing Configuration 2 on the depot operations, i.e., where all loads from the shuttle trailers are to be transshipped. Generally, the number of transferred loads increase, which leads to increased handling costs at the depot. Fritom's managers expressed that they expect the transportation cost reductions to exceed the expected additional handling costs at the depot by far. Nonetheless, any negative impact of the new collaborative transportation setting on the depots' operational performance should be mitigated. We recommend a small-scale re-design of the depots' internal layout and workforce planning to cope with the handling of loads from the shuttle trailers. The new layout should enable material handlers to quickly identify loads that need to be placed in the shuttle. Furthermore, implementing Configuration 2 requires a shift of the number of available material handlers over time.

Recommendation 4: Fritom's managers pointed to some challenges associated with the strongly dynamic number of shuttle trailers from day to day in Configuration 2. The corresponding fluctuation of resources required to operate the shuttle is their most pressing concern in that regard. Since the optimal shuttle capacity can only be determined shortly before the execution of the shuttle operations, it is difficult to arrange the required resources in time. Additional experimental analyses of Configuration 2 show that fixing the number of shuttle trailers does not lead to a strong performance reduction. The use of five shuttle trailers each day gives the best performance, resulting in a slight increase of 53,848 total kilometers (1.4%) with regard to the dynamic setting. Accordingly, operating 5 shuttle trailers can serve as an intermediary step towards full implementation of Configuration 2.

We finalized our research endeavor by presenting the above recommendations to Fritom's managers and by discussing the additional experimental and observational analyses. The managers validated our additional findings and agreed to implement the recommendations accordingly.

3.6 Discussion and future work

In this section, we identify areas for future research and innovations in practice. To that end, we consider the academic state-of-the-art, the current practice at Fritom, and the contribution and limitations of the solutions proposed in this chapter. First, we highlight Fritom's achievements in improving transport efficiency by means of collaboration and discuss further improvements realized by our alternatives. Subsequently, we propose areas for future research based on the limitations of our solutions and gaps left in the literature with regard to the GPDP.

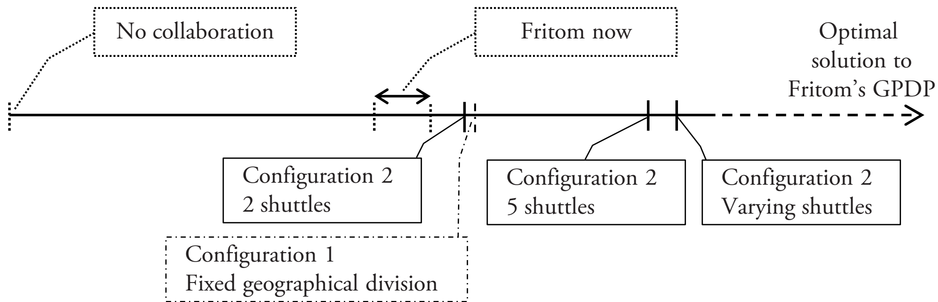

Figure 3.3: Scale of improvements towards the optimal solution to Fritom's GPDP

Figure 3.3 plots the efficiency improvements in domestic freight transportation as can be realized by Fritom through various collaborative structures. Furthermore, the figure emphasizes the quantitative support for Fritom's expectation that transport efficiency can be further improved by re-structuring and intensifying their current collaborative configuration. Specifically, we proposed and compared two alternative configurations that both focus on the delivery of loads that are redirected to a depot. The configuration with a variable geographical division (i.e., Configuration 2) significantly outperforms the configuration with a fixed geographical division (i.e., Configuration 1) at higher numbers of shuttle trailers. Accordingly, we recommend Fritom to implement Configuration 2. The IT tool developed to implement this configuration structures and intensifies Fritom's current collaborative configuration by supporting the planners in determining which, and how many, loads are to be allocated to the shuttle trailers. Due to the daily dynamics in load volumes and imbalance between both business units' sets of requests, the best number of shuttle trailers changes from day to day—as does the corresponding geographical division. Fritom could start their implementation of Configuration 2 by first operating a fixed number of 5 shuttle trailers since this avoids the need to arrange shuttle trailer resources dynamically and the efficiency gap is limited.

Our research leaves several opportunities for future research. Firstly, the proposed solutions for Fritom's collaborative transport planning can be refined and expanded to yield an even larger transport efficiency improvement. Currently, our best alternative configuration identifies loads that qualify for a transfer by means of a simple distance-based prioritization and allocates loads to shuttles in batches of a full trailer. This procedure can be refined by the design of a more sophisticated method for the identification and allocation. Furthermore, we adapted the nearest neighbor heuristic to emulate Fritom's operations. Whereas this resulted in low computational times for our problem (i.e., a single day is analyzed in a few seconds), the nearest neighbor can be improved by other vehicle routing heuristics (Solomon, 1987). Furthermore, the search for alternative collaborative configurations can be expanded by considering aspects that were left outside the scope of this research. Most notably, also the assignment of pickups to depots could be considered. We note that such an expansion increases the problem complexity dramatically due to the dynamics arising as a result of the need to consider multiple (unknown) planning periods.

Although transport efficiency can be considerably improved by means of an approach as outlined above, any collaborative approach can be outperformed by centralized joint route planning methods (Berger and Bierwirth, 2010; Wang and Kopfer, 2013). In the *theoretical background*, we defined the GPDP—being a class of pickup and delivery problems that matches this joint planning route planning problem. Promising areas for future research reside in the many aspects of the GPDP that are not yet addressed in the literature. Future research could develop solution methods to construct routes considering all GPDP fulfilment choices.

3.7 Conclusions

This chapter studies the collaborative transport planning between two autonomous business units of the Dutch logistics service provider Fritom. Since this planning problem does not fit any existing type of vehicle routing problems proposed in academic literature, we define a new problem class, called the *generalized pickup and delivery problem* (GPDP). Furthermore, we propose a solution approach to structure and improve Fritom's collaborative transport planning. Using an extensive real-world data set from Fritom, our experiments show that the proposed solution significantly outperform Fritom's current situation in terms of the total travel distance. We formulated managerial recommendations to guide Fritom in deploying the proposed solution. Lastly, we presented several avenues for future research and practical developments.

Chapter 4.

Synchronization in cross-docking networks: A research classification and framework

4.1 Introduction

Four commonly used strategies to configure a firm's distribution activities are direct shipment, milk-runs, warehousing, and cross-docking. In a direct shipment strategy, each shipment is sent directly from origin to destination. A milk-run strategy groups shipments into routes visiting multiple origins and destinations sequentially. These two strategies are associated with low implementation costs as they do not involve intermediary logistics facilities. When shipment sizes are small and customers are geographically dispersed, however, a direct shipment or milk-run strategy results in partially empty trucks and longer transportation lead times as products are stored further away from their demand points. In response to these shortcomings, firms can employ a warehousing or cross-docking distribution strategy.

Warehousing enables the consolidation of shipments to customers by assembling full truckloads from the products stored as inventory in a *warehouse* or *distribution center*. Stock can be efficiently replenished by ordering full truckloads from suppliers. At the warehouse, the main operations are to unload inbound trailers with products from suppliers, store the products, retrieve products and assemble them for shipment upon customer order, and dispatch the consolidated loads onto outbound trailers (Gu *et* *al.*, 2007). The existence of a storage buffer allows local warehouse operations to be considered largely in isolation from activities elsewhere in the distribution network. Hence, warehousing literature primarily addresses local warehouse problems (see, e.g., De Koster *et al.*, 2007; Gu *et al.*, 2007; 2010; Rouwenhorst *et al.*, 2000).

Instead of moving partially empty trailers or assembling loads from inventory, a cross-docking strategy groups shipments from multiple adjacent origins into full truckloads, which are then send to a *cross-dock* where they are unloaded and immediately recombined with loads sharing the same destination (Bozer and Carlo, 2008). As a result, cross-docking can realize transport efficiencies at reduced material handling and storage costs by eliminating the storage and order picking activities from the warehousing operations (Apte and Viswanathan, 2000; Gue, 2007). An important implication of employing a cross-docking strategy is that local operations at the cross-dock are tightly coupled with distribution activities elsewhere in the supply chain due to the absence of a storage buffer (Vogt, 2010). Therefore, the design and coordination of cross-docking operations requires a holistic approach, which aims to synchronize local and network-wide operations.

Decision models for the design and coordination of cross-docking operations are proposed in a considerable and fast-growing base of literature. Four recently published papers review this literature. Boysen and Fliedner (2010) focus on one important cross-docking problem, i.e., the scheduling of trailers at the cross-dock. Agustina *et al.* (2010), Stephan and Boysen (2011a) and Van Belle *et al.* (2012) present broader literature reviews. In these reviews, cross-docking literature is discussed by considering groups of papers addressing a similar decision problem, ranging from strategic design to operational planning. Despite the inherent interdependencies between local and network-wide cross-docking operations, none of the existing review papers discusses how different decision problems are actually related. The primary objective of this chapter is to fill that gap and advance from an understanding of solving isolated problems to an appreciation of the challenges inherent to solving cross-docking synchronization problems. To that end, this chapter presents a research classification and framework for synchronization in cross-docking networks.

This chapter is organized as follows. Section 4.2 presents our conceptualization of cross-docking. Section 4.3 defines six cross-docking problem classes and lists their constituent decision problems. A review and classification of cross-docking research is presented in Section 4.4. The research classification is used to understand the information needs for, and outputs from, each problem class. Based on this understanding, the framework for synchronization in cross-docking networks is proposed in Section 4.5. Section 4.6 demonstrates how the research classification and framework can be used to identify cross-docking synchronization problems with practical and scientific relevance. Lastly, Section 4.7 presents our conclusions.

4.2 Conceptualization

Many different definitions of cross-docking can be found in the literature. A review thereof reveals three common defining elements. Firstly, cross-docking definitions often contain a description of the basic operations performed at the cross-dock. In essence, incoming products are unloaded from inbound trucks, sorted based on their destination, moved through the cross-dock, and immediately dispatched onto outbound trucks. Secondly, most cross-docking definitions include a specification of the typical constraints and objectives associated with operations at the cross-dock. The most typical constraint in that regard is the limited time products stay inside the cross-dock, e.g., 24 hours. The aim for minimal material handling and the intention to limit the waiting times or tardiness of trailers and products at the cross-dock are frequently mentioned objectives. Thirdly, several cross-docking definitions address the purpose of a cross-dock in the distribution network. An important purpose of a cross-dock is to enable the consolidation of multiple less-than-truckload shipments to realize economies in transportation costs. At the same time, the rapid transshipment of products at the cross-dock should enhance the responsiveness of distribution logistics.

In this chapter, we emphasize the importance of including a broader network orientation when defining and conceptualizing cross-docking. Accordingly, our conceptualization considers local and network-wide cross-docking operations. *Local cross-dock operations* are conceptualized as the operations performed at the cross-dock; *network-wide cross-docking operations* as those performed elsewhere in the cross-docking network. We define a cross-docking network as the subsystem of a supply chain formed by one or more cross-docks, their inbound and outbound transport routes, and the stakeholders connected to the cross-docks by means of those routes. Various logistics facilities are identified as potential stakeholders in cross-docking networks. These logistics facilities include the typical supply chain entities (e.g., suppliers, manufacturers, warehouses, distribution centers, retailers, and customers) and can be located at the inbound and outbound side of the cross-dock. Below, we present a characterization for different cross-docking network configurations and address some industry specific implementations of cross-docking. We refer to Napolitano (2000) for a comprehensive industry-oriented introduction to cross-docking.

Figure 4.1 presents three typical configurations for cross-docking networks with a single cross-dock. Cross-docks in a *many-to-few network configuration* are often encountered in a manufacturing context, e.g., the automotive industry. Raw materials and components from many suppliers are consolidated at the cross-dock and sent to one of few nearby located manufacturing plants. The main purpose of the cross-dock in this setting is to enable a just-in-time supply of materials directly usable for manufacturing. Accordingly, value added logistics activities are often performed at the cross-dock in preparation of manufacturing. Due to the importance of cross-docks in these supply networks, manufacturers often invest in the automation of internal cross-dock operations.

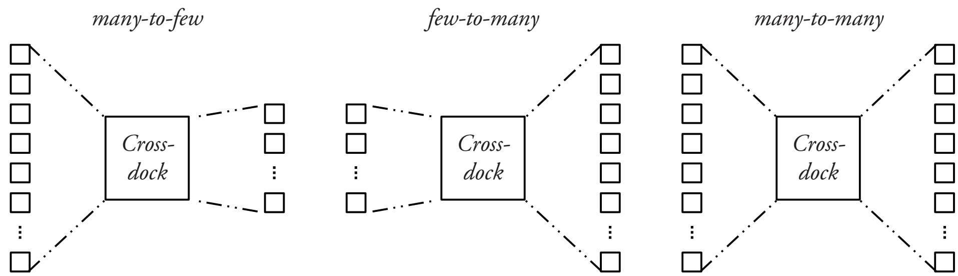

Figure 4.1: Network configurations with a single cross-dock

A *few-to-many network configuration* is common for cross-docks in retail distribution. At the cross-dock, incoming truckloads from a few distribution centers are split into delivery loads for a large number of retail stores. The cross-docking strategy of retailers usually originated from opportunistic cross-docking, i.e., where products bypassed the storage facilities at distribution centers only if the opportunity occurred.

Many retailers have developed their opportunistic cross-docking into a strategy purposely processing large cross-docking volumes, which are handled at a dedicated cross-dock area inside a distribution center. Operations at retail cross-docks are fully geared towards a reduction of inventory and distribution costs, while maintaining or improving responsiveness. The material handling systems inside most retail cross-docks allow for in-batch movement of shipments, since products are typically moved through the distribution network on homogeneous load-carriers, e.g., rolling containers.

A *many-to-many network configuration* is common for cross-docks in the less-than-truckload and parcel delivery industries. Parcel delivery companies transport many relatively small-sized packages, which justifies an automated conveyor system for material handling inside the cross-dock. By contrast, the larger-sized and strongly varying shapes of products that flow through the cross-docks of less-than-truckload carriers necessitate a flexible material handling system—typically formed by manually operated forklift trucks.

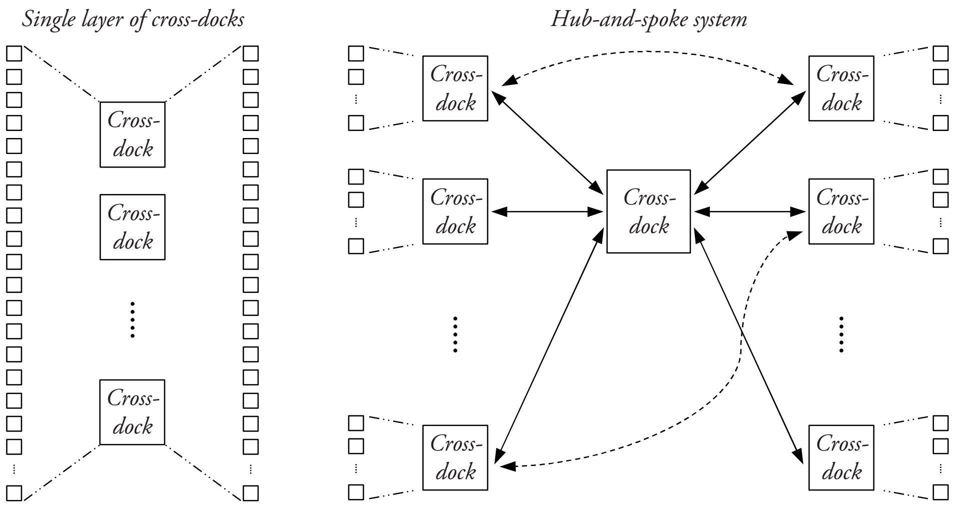

Figure 4.2: Network configurations with multiple cross-docks

Figure 4.2 shows two prototypical network configurations that include multiple cross-docks. In cross-docking networks with a *single layer of cross-docks*, shipments are often allocated to one of the cross-docks. Moreover, opportunities can be sought to transport the shipment directly from origin to destination—bypassing all cross-docks in the network. Variants of this network configuration are often employed in the supply chains of large retailers and manufacturers. Another well-known network configuration with multiple cross-docks is the *hub-and-spoke system*. In this configuration, shipments can be allocated to multiple cross-docks in succession. Hub-and-spoke systems are often employed by less-than truckload carriers or parcel delivery companies.

We conceptualize *synchronization* in cross-docking networks as the coordination of local cross-dock operations and network-wide logistics while acknowledging their strong interdependency. That is, synchronization addresses the tight coupling of inbound transportation, local cross-dock operations, and outbound transportation that exists as a result of the absence of a storage buffer inside the cross-dock. In the subsequent sections, this chapter builds towards specific suggestions for future research to take these interdependencies into account when developing cross-docking decision models.

4.3 Cross-docking problem class definitions

This chapter is the first to identify and define 24 individual decision problems, which, collectively, reflect the full scope of cross-docking design and coordination. We identified the decision problems by first deriving all decision variables from the models proposed in the reviewed journal papers. Next, a set of distinct decision problems was developed by analyzing whether variables address a similar decision. Finally, we compared the complete set of decision problems with our observations in practice. The decision problems that were observed in practice, but not reflected by a decision variable in cross-docking literature, were formulated based on a review of related research areas, such as warehouse design (De Koster *et al.*, 2007; Gu *et al.*, 2010), warehouse operations and control (Gu *et al.*, 2007; Rouwenhorst *et al.*, 2000), distribution network design (Alumur and Kara, 2008; Melo *et al.*, 2009), and distribution network planning (Crainic, 2000).

The individual decision problems originate either locally at the cross-dock or elsewhere in the cross-docking network. Local and network-wide decision problems can be further distinguished by their decision making level, i.e., strategic, tactical, or operational. We used these distinguishing factors to cluster the individual decision problems into six problem classes as presented in Table 4.1. The cross-docking problem classes are described below and defined by their constituent individual decision problems—as summarized in Table 4.2. References to studies in each problem class are discussed in Section 4.4.

Table 4.1: Cross-docking problem classes

	Local cross-dock management	Cross-docking network management
Strategic	Cross-dock design	Network design
Tactical	Cross-dock planning	Network planning
Operational	Cross-dock scheduling	Network scheduling

Cross-dock design: Cross-dock design decisions specify the contour of the cross-dock and determine the configuration of its interior. The main aims are to enable rapid transshipment and provide sufficient capacity to meet freight throughput requirements. An important design decision determines the required number of dock doors. *Strip doors* (or inbound doors) are used for unloading arriving trailers; whereas *stack doors* (or outbound doors) are used for loading departing trailers. A typical cross-dock design places dock doors closely together around the perimeter of the facility. Therefore, the shape of the cross-dock dictates the relative distances among dock doors, and hence influences the efficiency at which shipments can be moved from strip to stack doors.

The capacity and efficiency of the cross-dock is also determined by the configuration of the area inside the cross-dock. Usually, not all inbound shipments can be directly reloaded onto an outbound trailer. Inside the terminal, most cross-docks consist of an open area where shipments can be sorted and temporarily placed on the ground to facilitate consolidation activities. This area is referred to as the *staging area*. A typical staging area design enables the temporarily stored shipments to be easily accessed and ensures fast movement of those shipments to their outbound trailers. The automation level of the material handling equipment is another important internal cross-dock design aspect.

Cross-dock planning: Cross-dock planning decisions address local cross-dock operations on the medium-term. A typical objective used by cross-dock managers is to minimize the material handling effort required for moving incoming freight from strip to stack doors. The decision specifying dock doors as either strip or stack door dictates the aggregated freight flows through the cross-dock. More precise freight flows are determined by the dock door assignment, i.e., demining at which dock door a trailer is served. Cross-docks serving a fixed set of origins and destinations with relatively constant freight flows tend to assign dock doors over a planning horizon of 3-6 months. In situations with more volatile freight flows, stack doors are sometimes assigned from night to night. A dynamic assignment of docks doors requires contemporary information technology (e.g., RFID) supporting the material handlers in locating the stack doors associated with shipments.

Another important cross-dock planning decision is concerned with determining the appropriate workforce and material handling equipment to efficiently handle all freight within the limited time available. Cross-dock operations start and end with little or no shipments in the staging area and usually take place during a part of the day, e.g., overnight.

Cross-dock scheduling: Cross-dock scheduling decisions specify the allocation of resources at the cross-dock over time. Scheduling decisions for serving trailers at the cross-dock are aimed at facilitating a smooth flow of freight from the strip to the stack doors. As opposed to the assignment of dock doors, trailer scheduling decisions consider highly capacity constrained dock doors, i.e., the number of trailers to be served considerably exceeds the number of available dock doors. Accordingly, detailed timing and sequencing aspects are taken into account in order to minimize the waiting times of shipments and trailers on-site. Trailer schedules can be completed before the start of operations or developed dynamically during ongoing operations. This is referred to as *offline* or *online* trailer scheduling, respectively. In order to align the inbound and outbound activities at the cross-dock, the internal workforce that unloads and reloads trailers and moves freight through the cross-dock has to be scheduled as well.

The utilization of the staging areas (i.e., how shipments are placed in the staging area) influences the total travel distance of the material handling equipment and determines the accessibility of shipments. Lastly, some cross-docks receive inbound products that are not yet assigned to a particular outbound trailer. Cross-dock scheduling then involves the assignment of products to outbound trailers, i.e., assembling consolidated trailer loads.

Network design: Network design decisions determine the physical infrastructure of the cross-docking network such that transportation demand is met at the lowest possible costs. Each request for transportation is associated with particular costs, which are incurred depending on how that request is routed through the cross-docking network. An important network design decision is concerned with shaping the general structure of the network and defining the types of logistics facilities that are established. The structure of the network consists of a set of possible facility locations and routes to transport freight. The facility type definitions describe for each type, e.g., the fixed costs to operate the facility, the maximum capacity, and the distribution functions performed. Opportunities for outsourcing may also emerge—and are evaluated—when the network structure is shaped and the facility types are defined. Based on the network structure and the expected transportation demand, the appropriate number and locations of facilities in the cross-docking network are determined as part of the network design.

Network planning: Network planning decisions are concerned with allocating and utilizing network-wide logistics resources in order to attain economic and customer service level objectives. A primary network planning decision assigns transport capacity (e.g., a fixed number of trailers) to each route in the cross-docking network and, thereby, specifies which of the potential network routes will actually be used to provide transport services. A closely related network planning decision allocates freight to the available transport services.

Collectively, the network planning decisions determine how freight is routed through the network, and thus where opportunities for consolidation occur. If transportation demand is characterized by shipments with origin-destination pairs, the destination for each shipment is known prior to solving the network planning problems. Alternatively, transportation demand is expressed by supply and demand figures for one or more product types. The decision to assign a destination to each product is then part of the network planning. Provided that the correct product range is sent to each destination, products from the same type are interchangeable. The decision latitude that may arise as a result of product interchangeability, effectively, enables additional opportunities for consolidation.

Network scheduling: In contrast to network planning decisions, network scheduling considers detailed temporal constraints in routing freight through the cross-docking network. The capacity and time windows for transport services in the cross-docking network are often determined in advance of the scheduling decisions. Network scheduling is then concerned with dispatching shipments, i.e., specifying if and how many shipments are dispatched onto a given transport service. In the local region of a cross-dock, network scheduling may include vehicle routing to collect and deliver shipments from and to the cross-dock. In this specific variant of the vehicle routing problem, there is an emphasis on aligning the resulting inbound and outbound freight flows at the cross-dock.

Table 4.2: Clustering of the individual cross-docking decision problems

Problem class	Individual decisions problems
Network design	• Network structure and facility types • Number of cross-docks • Location of cross-docks
Cross-dock design	• Shape of the cross-dock • Number of dock doors • Capacity of staging area • Design of staging area • Automation of material handling equipment
Network planning	• Capacity planning for network routes • Freight flow allocation • Shipment to destination assignment
Network scheduling	• Shipment dispatching • Collection and delivery vehicle routing
Cross-dock planning	• Dock door specification • Strip door assignment • Stack door assignment • Equipment and workforce capacity planning
Cross-dock scheduling	• Offline scheduling of inbound trailers • Online scheduling of inbound trailers • Offline scheduling of outbound trailers • Online scheduling of outbound trailers • Internal cross-dock workforce scheduling • Staging area utilization/shipment allocation • Shipment to outbound trailer assignment

4.4 Literature review and classification

Despite the separate introduction of the problem classes in the previous section, cross-docking design and coordination issues in practice often consist of multiple individual decision problems from different problem classes. If a particular cross-docking problem is concerned with multiple strategic, tactical, and/or operational problem aspects, one should bear in mind the *hierarchical* interdependencies between the decision-making levels. In addition to these hierarchical interdependencies, this chapter emphasizes the existence of *lateral* interdependencies (i.e., between local and network-wide problem aspects). We argue that the lateral interdependencies are particularly important in the design and coordination of cross-docking operations due to the absence of a storage buffer inside a cross-dock.

The literature review and classification approach are geared towards identifying and understanding the hierarchical and lateral interdependencies among the cross-docking problem classes. To this end, we analyze for each problem class which input parameters and constraints are addressed and how they are related to the outputs of individual decision problems in other problem classes. Moreover, we study the characteristics of the decision model outputs from each cross-docking problem class.

4.4.1 Sample selection and classification procedure

We conducted a search in Google Scholar to identify journal papers on cross-docking published before 2014—using *cross dock* and *cross-docking* as keywords. Papers in all international peer-reviewed journals were considered for inclusion in our sample. First, we scanned the titles and abstracts of the papers and included a paper only if it proposes a mathematical model for one or more cross-docking decision problems. Accordingly, descriptive and normative cross-docking studies (e.g., Apte and Viswanathan, 2000; Vogt, 2010) as well as papers providing analytical models to evaluate the benefits of employing a cross-docking strategy or compare different types of cross-docking operations (e.g., Alptekinoğlu and Tang, 2005; Yan and Tang, 2009) were left outside the scope of our classification. Subsequently, we examined the remaining papers more closely and excluded papers proposing models that consider the deployment of some cross-docking principles inside a manufacturing plant (e.g., Hauser and Chung, 2006) or traditional warehouse (e.g., Choy *et al.*, 2012). We also checked the references of all papers in our sample and used Google

Scholar's *cited by* function (i.e., forward citation tracking) to identify any papers we might have missed in our initial search. The search and selection procedure resulted in 76 journal papers from a wide-range of Operations Research journals.

Upon classification, we specify for each of the selected papers which of the individual decision problems are considered and whether they are considered as an input or output. Papers are clustered based on the outputs of the proposed decision models. If the model solves one or multiple individual decision problems from a single problem class, we consider the paper to address an *isolated* cross-docking problem. If the model solves decision problems from multiple cross-docking problem classes, we consider the paper to address an *interrelated problem area*. The precise classification procedure and the resulting classification table are presented in Section 4.4.5. Prior to that, the following sub-sections concisely describe the reviewed papers.

4.4.2 Local cross-dock management

Below, we discuss papers addressing a problem that occurs locally at the cross-dock.

Cross-dock design

Three papers were identified that focus on the design of cross-docks. Bartholdi and Gue (2004) determine the optimal shape for a cross-dock under different operating conditions. The different conditions are generated by varying the values of four characteristics: the number of dock doors, the freight flow pattern, the proportion of strip-to-stack doors, and the dock door assignment. The cross-dock shapes considered are I, L, T, H and X. Each shape is evaluated according to its associated labor costs, which is estimated using a metric for the average travel distance of material handling equipment. The authors conclude that as the number of dock doors increase, the most labor-efficient shapes for a cross-dock are I, T, and X, successively. One practical implication from this study is that an I-shaped cross-dock can best be expanded into a T-shape when approaching 150 dock doors, and should be further expanded into an X-shape at approximately 200 dock doors or more. In a similar design study, Carlo and Bozer (2011) focus on rectangular cross-docks. The authors analytically show that a narrow-shaped cross-dock minimizes the expected travel distance of material handling equipment if the perimeter of the cross-dock is fixed; whereas a square shape is best if the area of the cross-dock is fixed. Considering a cross-dock with an equal number of strip and stack doors, the authors obtain the optimal dock door assignment for different freight flow patterns.

Vis and Roodbergen (2011) study a different cross-dock design problem, which is aimed at designing the staging areas inside a cross-dock. The authors propose a dynamic design procedure which is constrained by several physical restrictions imposed by the shape of the cross-dock. The proposed procedure emphasizes the interplay between the design of the staging area and the policies by which employees temporarily place and pick shipments to or from that staging area.

Several potential research avenues for cross-dock design still exist, particularly regarding the cross-dock's interior. The internal design of a cross-dock greatly affects the ability to efficiently sort shipments and move them from inbound to outbound trailers; yet it remains a fundamental challenge for many cross-dock managers. Determining the optimal location for value adding logistics activities (e.g., labeling, pricing and re-packaging) inside the cross-dock further adds to the complexity of this design problem, and hence would form a significant research contribution. Furthermore, most cross-dock design studies assume that manually operated forklift trucks move the freight from inbound to outbound trailers. However, highly automated material handling systems for cross-docks recently became available. Future cross-docking research could be aimed at quantifying the benefits of using automated cross-dock systems in order to weigh those benefits against the loss of flexibility associated with using such automated systems.

Cross-dock planning

All identified cross-docking planning papers focus on the dock door assignment problem. Tsui and Chang (1990; 1992) consider a variant of this problem in which the aim is to assign each stack door to a destination and each strip door to an origin over a mid-term planning horizon. Cohen and Keren (2009) argue that high volume destinations often require multiple trailers to be loaded simultaneously. Accordingly, the authors extend the approach of Tsui and Chang (1990; 1992) by allowing multiple stack doors to be assigned to each high volume destination.

The authors of the above papers considerably limit the search space of the dock door assignment problem by assuming stack and strip doors are readily specified on opposite sides of the cross-dock. Stephan and Boysen (2011b) study the impact of this pre-determined dock door specification on the dock door assignment problem by comparing it to the situation where strip and stack doors can be specified freely around the perimeter of the facility. The study shows that the two policies differ in dock door assignment flexibility, complexity of the freight flows, and potential for congestion inside the cross-dock. It is concluded that a pre-determined specification of dock doors on opposite sides of the cross-dock leads to inferior operational performance in most cases, except when information about inbound loads is lacking.

Oh *et al.* (2006) propose a policy that clusters destinations and assigns multiple adjacent dock doors to each of these clusters. The clustering of destinations promises reduced internal travel distance by enabling additional grouping of inbound freight for movement inside the cross-dock. Oh *et al.* (2006) make the strong assumptions that all inbound freight enters the cross-dock through one strip dock door and that the material handling equipment can handle batches of inbound shipments.

Many cross-docks receive inbound freight from a large and constantly changing set of origins, which makes the assignment of strip doors on a medium term planning horizon infeasible—and often undesirable. Accordingly, Bartholdi and Gue (2000) formulate a dock door assignment problem assuming a first-come-first-serve (FCFS) policy for allocating inbound trailers to strip doors. The proposed approach first specifies any dock door as either a strip or stack door and then assigns the stack doors to destinations. The aim is to minimize the workforce required to move all inbound shipments to their corresponding outbound trailers. Rather than using rectilinear distances alone, queuing theory is applied to calculate the weighted moving time, which delicately balances travel distance with congestion imposed by floor space constraints, forklift interference and dragline congestion.

Bartholdi and Gue (2000) assume that, over time, a FCFS policy for the allocation of inbound trailers yields a freight flow through each individual strip door that tends to resemble the aggregate flow of freight through the cross-dock. Accordingly, the authors model all inbound trailers as *average trailers*. Due to daily variations in freight flows, however, the assumption of average trailers may result in dock door assignments that are optimal over the selected planning horizon, but yield very poor results for individual days within that horizon. Gue (1999) argues that the use of look-ahead scheduling enables cross-dock operators to allocate inbound trailers to strip doors based on the information about the destinations of their shipments. The author proposes a model to specify dock doors and assign destinations to stack doors based on inbound freight flows that are modeled as *biased trailers*. The use of biased trailers is based on the premise that cross-dock operators use information about the content of inbound trailers to allocate those trailers to a strip door as closely as possible to the stack door to which most of its content has to be moved.

Bozer and Carlo (2008) extend the work of Bartholdi and Gue (2000) and Gue (1999) by taking into account the performance effects of daily variations in freight flows. The authors first propose a static model for assigning stack doors. A second, dynamic model uses detailed freight flow information to daily assign strip and stack doors. Since this paper presents two distinct models, it appears twice in Table 4.3. Yu *et al.* (2008) study a dock door assignment problem very similar to Bozer and Carlo (2008), but propose a sequential solution approach that first assumes a fixed stack door assignment to develop a scheduling policy for inbound trailers and then optimizes the stack door assignment based on that policy. The scheduling policy emulates the inbound scheduling decisions made by the cross-dock operators.

The above cross-dock planning procedures provide ample methodologies for solving the dock door assignment problem. The procedures that consider the effects of freight flow variations are particularly valuable for cross-docking practice. All dock door assignment studies assume the equipment and workforce required to move shipments through the cross-dock either to be always available when needed or to be constrained by a given capacity. In practice, cross-dock managers often face considerable difficulty in determining the appropriate equipment and workforce capacity over a mid-term planning horizon. Accordingly, future cross-dock planning research could develop methodologies that simultaneously address the assignment of dock doors with the planning of equipment and workforce.

Cross-dock coordination

We identified two recently published papers that add cross-dock scheduling aspects to the dock door assignment problem. Chmielewski *et al.* (2009) propose a model assigning stack doors to destinations and determining a schedule for the inbound trailers while considering multiple internal cross-dock capacity limits. The aim is to minimize the internal travel distance of material handling equipment and the waiting time of inbound trailers. Luo and Noble (2012) propose a model that assigns strip doors to origins and stack doors to destinations. Moreover, the model assigns shipments to outbound trailers, positions shipments in a staging area when needed and determines the departure times for outbound trailers. The authors assume the arrival time distribution for inbound trailers to be known and inbound trailers to be served directly upon arrival at the strip door which is assigned to their origin.

We identify a promising research trend with regard to recent studies integrating cross-dock planning aspects (i.e., dock door assignment) with cross-dock scheduling aspects, such as trailer scheduling and positioning of shipments inside the staging area. Nonetheless, there is ample opportunity to continue this line of research. Firstly, this type of research is still in its infancy. Hence, the current problem descriptions and solution approaches are formulated only for a limited number of (rather specific) cross-dock application domains. Secondly, other cross-dock scheduling aspects could be integrated with cross-dock planning, as will become clear in the subsequent discussion on cross-dock scheduling literature.

Cross-dock scheduling

The vast majority of cross-dock scheduling studies are aimed at solving trailer scheduling problems. Fourteen of those studies consider variants of a highly simplified scheduling problem aimed at deriving fundamental insights that might also apply to more realistic problem settings. Most of these studies consider a cross-dock with one strip door, one stack door and infinite staging area capacity (Arabani *et al.*, 2010; 2011a; 2011b; 2012; Boysen *et al.*, 2010; Forouharfard and Zandieh, 2010; Larbi *et al.*, 2011; Liao *et al.*, 2012; Vahdani and Zandieh, 2010; Yu and Egbelu, 2008). Vahdani *et al.* (2010) and Soltani and Sadjadi (2010) consider a cross-dock that does not allow staging. The proposed models determine the sequence in which the inbound and outbound trailers are served and assign shipments to outbound trailers. In an otherwise similar cross-dock setting, Chen and Lee (2009) assume each inbound shipment to be assigned to a specific outbound trailer already upon arrival. Briskorn *et al.* (2010) study a rather different variant of the simplified trailer scheduling problem, where the cross-dock handles homogeneous products through a single dock door that can be utilized both as strip and stack door.

Whereas the above studies provide interesting insights, direct practical applicability is low as most real-world cross-docks comprise multiple strip and stack doors. In response, several studies have considered cross-docks with multiple dock doors, while focusing on the scheduling of either inbound or outbound trailers. Alpan *et al.* (2011a; 2011b) determine a schedule for serving outbound trailers at multiple stack doors, making the assumption that the arrival sequence of inbound trailers is fixed and that they are served at the strip doors according to a FCFS policy.

Boysen and Fliedner (2010) and Boysen *et al.* (2013) determine a schedule for inbound trailers in a cross-dock setting with a given outbound trailer schedule. Inbound shipments are assumed to be assigned to outbound trailers upon arrival. Variants of this trailer scheduling problem include internal workforce capacity constraints (Rosales *et al.*, 2009), cope with inbound trailer arrival times that are not exactly known (Acar *et al.*, 2012; Konur and Golias, 2013a; 2013b), or consider also the assignment of shipments to outbound trailers (Liao *et al.*, 2013). McWilliams (2009b; 2010), McWilliams *et al.* (2005; 2008) and McWilliams and McBride (2012) address the scheduling of inbound trailers in a setting where inbound shipments are transferred to readily available outbound trailers by means of a network of conveyors connecting all docks doors. The specification of dock doors as either strip or stack door and the assignment of stack doors to destinations are assumed to be known in advance. Moreover, it is assumed that outbound trailers depart when fully loaded and are immediately replaced with an empty one. These problem particularities allow the outbound trailer schedule to be ignored. An online scheduling model for the same problem context is proposed in McWilliams (2009a). Wang and Regan (2008) propose two online procedures for the scheduling of inbound trailers in a more typical cross-dock setting. The authors assume the dock door specification and the assignment of stack doors to destinations to be known and the internal cross-dock workforce to be always available when needed.

Miao *et al.* (2009) were the first to consider the scheduling of both inbound and outbound trailers in a setting with multiple dock doors. The authors assume that dock doors can be used as strip and stack door upon availability and consider pre-determined arrival and departure times for all trailers. Accordingly, the aim is to allocate trailers to dock doors while minimizing the number of unfulfilled shipments.

Other studies that determine schedules for inbound and outbound trailers at cross-docks with multiple dock doors assume the doors to be specified as either strip or stack door prior to the trailer scheduling. Chen and Song (2009) extend the single strip and single stack door setting proposed in Chen and Lee (2009) into a multiple door problem. The proposed solution approach first determines a good inbound trailer schedule and then identifies an optimal outbound trailer schedule for that particular inbound schedule. Variants of this problem consider shipments that cannot be temporarily staged inside the cross-dock (Boysen, 2010) or shipments that are not yet assigned to particular outbound trailers upon arrival (Joo and Kim, 2013). Van Belle *et al.* (2013) simultaneously schedule inbound and outbound trailers. Their approach aims to minimize the tardiness of trailers and the time needed to move all shipments between dock doors. Shakeri *et al.* (2012) propose a cross-dock scheduling approach that considers a capacity constrained internal workforce, and hence takes internal cross-dock scheduling into account when determining the inbound and outbound trailer schedules. In their current solution approach, the authors adopt a simple policy for positioning shipments in the staging area and dedicate one forklift operator to each stack door for moving shipments from their inbound to their corresponding outbound staging areas. The proposed model is designed to include more complex internal cross-dock schedules in the future.

Another, much smaller group of papers considers the resource scarcity associated with local cross-dock operations. Li *et al.* (2004) and Álvarez-Pérez *et al.* (2008) propose very similar procedures to schedule a resource-constrained workforce that breaks down inbound truckloads and assembles loads for outbound shipment. Vis and Roodbergen (2008) propose a procedure to find the best position for temporarily placing shipments in the staging area. In order to find that position, the authors consider the additional travel distance incurred when the material handling equipment has to deviate from the shortest path associated with directly placing a shipment onto its outbound trailer. The strip and stack door assignments are assumed to be known, as is the destination for each inbound shipment.

In sum, there is a large and fast-growing body of literature on cross-dock scheduling problems in general, and on the scheduling and sequencing of trailers in particular. The above overview of literature in that area highlights the breadth of specific decisions involved in local cross-dock scheduling. It also shows that existing literature primarily studied simplified problems—considering a limited number of decision problems and making strong assumptions regarding the specific cross-dock setting addressed. Furthermore, most of these studies focus on minimizing the length of the cross-dock operations, i.e., the makespan. The workforce and material handling equipment required to move shipments from inbound to the outbound trailers are often neglected. Nonetheless, cross-dock planning studies indicate that the total distance traveled and the congestion that appears on-route between dock doors are important factors in the operational performance of a cross-dock. Therefore, future cross-dock scheduling research could consider staging policies and congestion measures to more accurately translate the distance among dock doors into the travel and waiting time of shipments inside the cross-dock. The recent study of Shakeri *et al.* (2012) is promising in that regard as it considers workforce scheduling and staging policies when determining trailer schedules. Future cross-dock scheduling research is encouraged to extend the work of Shakeri *et al.* (2012) by including more complex internal scheduling policies.

4.4.3 Cross-docking network management

This sub-section is analogous to Sub-Section 4.4.2, except it discusses papers addressing problems originating elsewhere in the cross-docking network. We note that most cross-docking network methodologies fall within the remit of general transportation network research (see e.g., Crainic, 2000; Eksioglu *et al.*, 2009; Melo *et al.*, 2009). Whereas the authors of cross-docking network papers make the explicit or implicit assumption that the absence of long-term storage inside cross-docks distinguishes their problems from general network problems, they generally remain silent on which problem aspects actually differ—and how. We expect the most fundamental differences to be prevalent in research areas where local and network-wide cross-docking problems are considered simultaneously. Accordingly, in our discussion of the papers below, we refrain ourselves from formulating detailed suggestions for future research considering cross-docking network aspects alone. Rather, we encourage scholars to differentiate cross-docking network research from general transportation network design and coordination literature by adopting a synchronization focus, i.e., specifically aimed at simultaneously solving local cross-dock and network-wide decision problems.

Network design

We identified seven papers with a focus on cross-docking network design, which are primarily aimed at determining the best cross-dock locations. Determining the optimal location of cross-docks and other facilities in a cross-docking network strongly depends on how freight flows are distributed over those facilities. Therefore, the locations of the cross-docks are often determined simultaneously with the allocation of freight flows. In general facility location literature, this combined problem is referred to as the *location-allocation problem* (Alumur and Kara, 2008). Bhaskaran (1992) was among the first to study this problem in a cross-docking network context and focused on determining the optimal number and location of multiple cross-docks. The proposed approach solves a continuous facility location problem for different numbers of cross-docks and includes practical considerations, such as minimum-size requirements for cross-docks.

Other cross-docking network design literature proposes discrete network models, which determine the optimal number and locations of cross-docks from a set of pre-identified candidate locations. Each location is associated with a fixed cost for establishing or operating a cross-dock. The main decisions for these models are concerned with whether or not to establish a cross-dock at each of the candidate locations and how the freight flows are allocated to the cross-docks in the network. In addition to these decisions, the discrete network design models proposed by Sung and Song (2003) and Sung and Yang (2008) determine on-route capacity by allocating vehicles to each of the network routes. Freight flows are allocated such that all shipments are handled by exactly one cross-dock. The capacity of each cross-dock is constrained by a given maximum number of transshipments. Gümüs and Bookbinder (2004) study a similar discrete cross-docking network design problem, but allow the identification of opportunities for direct shipment before solving the location-allocation problem based on the remaining shipments. Mousavi and Moghaddam (2013) not only consider the location-allocation problem, but also determine the collection and delivery vehicle routes.

The aforementioned network design problems address the cross-docking network configuration with a *single layer of cross-docks*. Another set of papers that focus on cross-docking network design take a broader supply chain perspective. Jayaraman and Ross (2003) and Ross and Jayaraman (2008) propose a network design approach determining not only the number and locations of cross-docks in the network, but also that of the warehouses supplying the inbound shipments to the cross-docks. Bachlaus *et al.* (2008) study a very similar network design problem and include various aspects associated with the manufacturing plants and suppliers of raw materials, e.g., their production capacity and volume flexibility. The broader supply chain network design approaches consider the capacity of a cross-dock in terms of the number of product families they can handle.

Network planning

We identified only one paper that addresses cross-docking network planning aspects alone. Musa *et al.* (2010) propose a model that assigns capacity to the available network routes (in terms of a number of vehicles) and allocates freight flows to those routes. Freight flow constraints and costs for operating network routes are assumed to be known. The proposed model allows freight to be routed either directly from origin to destination or pass through one of the cross-docks in the network. Cross-dock capacity constraints are not considered.

Network coordination

Network planning approaches do not take temporal constraints into account, and hence assume that individual shipments can always be consolidated as long as they are transported within the same planning interval. We identified six papers that present more realistic network coordination approaches by incorporating network scheduling aspects, i.e., consider also detailed resource and temporal constraints in identifying opportunities for consolidation. More specifically, these papers simultaneously address shipment dispatching and network planning decisions. Lim *et al.* (2005) present problem formulations for several variants of this problem, assuming that the capacity and time window constraints for each transport service are known a priori. One of those variants is addressed by Chen *et al.* (2006). In this problem, the network consists of multiple cross-docks and each shipment should be handled at exactly one cross-dock. Transportation demand is characterized by supply and demand figures for multiple product types. Besides solving the shipment dispatching and freight flow allocation problem, the proposed approach assigns a destination to the products upon arrival at the cross-dock. Ma *et al.* (2011) consider a similar problem, but consider only one product type. In addition, the shipments may also be routed directly to the customer, i.e., bypassing all cross-docks.

The above network coordination studies model all time windows as hard constraints. As a result, there may be unfulfilled shipments in the case that one or more transportation services cannot be accomplished within the given time window constraints. Due to the penalties associated with these unfulfilled shipments, solutions are likely to provide a less efficient schedule in order to meet the hard time constraints. In response to this issue, Miao *et al.* (2012) and Marjani *et al.* (2012) extend the above problems by considering also soft time constraints. In Miao *et al.* (2012), collections are forced to be always performed within the given time windows while customer demand may be served with a delay—albeit additional penalty costs are incurred. Reversely, Marjani *et al.* (2012) allow the collection time window constraints to be violated. Erera *et al.* (2013) include temporal constraints in another way. Assuming fixed and known freight flows, a three-phase procedure is proposed to find an optimized route for each shipment. In the first phase, the model assigns capacity to each network route by constructing time-space feasible bundles of consolidated shipments. In the second phase, a dispatch window is assigned to the consolidated shipments bundles created in the first phase. The third phase assigns truck drivers to the routes determined in the second phase.

Network scheduling

We identified four papers that address a network scheduling problem. Hernández *et al.* (2011) consider a network scheduling problem in a setting with centralized network coordination, i.e., a central network coordinator makes the network planning decisions. In their problem, an individual freight carrier can acquire capacity from a collaborative partner when its own fleet has insufficient capacity to meet transport demand. The authors assume that network planning decision outcomes are known in advance and represented by the time-dependent availability of the collaborative transport service capacities in the network. The proposed model dynamically determines how the cross-dock operator could best dispatch shipments onto the collaborative network routes when aiming for timely deliveries.

The other cross-docking network scheduling problems consider a decentralized network coordination setting, i.e., the cross-docking network consists of multiple subsystems and each cross-dock manager coordinates the transport services in his own subsystem. In a typical decentralized setting, a cross dock manager performs network scheduling by determining the collection and delivery vehicle routes for the shipments in his particular subsystem. This variant of the vehicle routing problem differs from the vast body of knowledge on classical vehicle routing problems by its emphasis on aligning inbound and outbound freight flows at the cross-dock. We refer the reader to Eksioglu *et al.* (2009) for a taxonomy of vehicle routing problem variants. Lee *et al.* (2006), Liao *et al.* (2010), and Vahdani *et al.* (2012) address a cross-docking variant of the vehicle routing problem assuming that the alignment of freight flows at the cross-dock necessitates a simultaneous arrival and departure of all inbound and outbound vehicles. Santos *et al.* (2013) model a very similar problem as a pickup and delivery problem with a single cross-dock. As opposed to the aforementioned approaches, the decision model proposed by Santos *et al.* (2013) allows vehicle routes to either visit the cross-dock or not. We refer the reader to Berbeglia *et al.* (2007) for a classification of pickup and delivery problem variants.

4.4.4 Synchronization

Effective cross-docking requires local and network-wide operations to be synchronized. The corresponding interdependencies between cross-docking problem classes may occur at the strategic, tactical, and operational level.

We could identify only three papers considering lateral interdependencies—all at the operational level. Hu *et al.* (2013) and Wen *et al.* (2009) focus on determining the collection and delivery vehicle routes, while acknowledging the interdependencies that emerge between those routes when vehicles have to unload or reload shipments at the cross-dock. Accordingly, these authors consider the local cross-dock decision concerned with assigning shipments to particular outbound trailers. The assignment of shipments to outbound trailers is interdependent with the vehicle routing as delivery routes can only depart from the cross-dock when all its loads have arrived by means of collection routes. Tarantilis (2013) studies a similar problem in which all shipments have to be unloaded and reloaded at the cross-dock.

No papers were identified that consider strategic or tactical interdependencies. We refer the reader to Section 4.6 for suggestions for future cross-docking synchronization research at different levels of decision-making.

4.4.5 Research classification

The research classification is detailed in Table 4.3. The columns cover the individual cross-docking decision problems and are clustered according to the six problem classes. The rows represent the papers discussed in the sections above. We classified each paper based on the individual decision problems it considers. The decision problems that are part of the output of a proposed model are classified in the table with the character *O*. The character *I* indicates that the model assumes that the result of the particular decision problem to be known in advance, i.e., either as input parameter or as constraint. The character *Z* denotes the case when the input is assumed to be zero. Decision problems that are not considered in the proposed model are classified with the character *.

The classification of the papers is based on the outputs of the proposed decision model and represented by the clustering of multiple rows in Table 4.3. If the proposed model includes one or multiple individual decision problems from a single problem class as output, we consider the paper to address an isolated cross-docking problem. If the model includes outputs from multiple cross-docking problem classes, we consider the paper to address an interrelated problem area.

Figure 4.3 summarizes the classification. The numbers in the figure represent the accounted publications in each isolated problem class or interrelated problem area. One can observe that the overwhelming majority of papers address an isolated cross-docking problem, i.e., proposing a decision model solves one or more individual decision problems within the same cross-docking problem class. The papers that do address an interrelated problem area mostly hierarchically integrate strategic, tactical, and operational problem aspects, considering either a local cross-dock or a network problem setting. While valuably in itself, such integrative research efforts do not consider the strong lateral interdependencies between local and network-wide operations inherent to the cross-docking strategy.

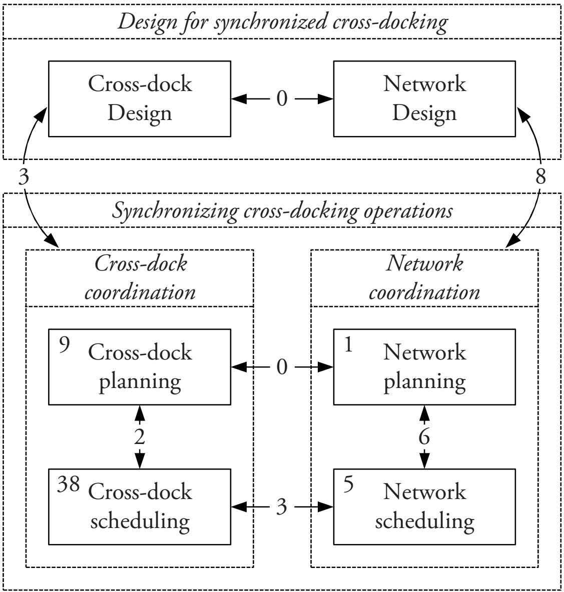

Figure 4.3: A summary of the research classification

Besides summarizing the research classification, Figure 4.3 also highlights potential interdependent cross-docking problem areas. Regarding the hierarchical interdependencies, *cross-dock coordination* problems consist of planning and scheduling aspects of decision problems that originate locally at the cross-dock. Similarly, *network coordination* problems consist of network planning and scheduling aspects. Existing cross-dock and network design models generally consider hierarchical interdependencies with cross-dock and network coordination aspects. Regarding the lateral interdependencies, Figure 4.3 shows two potential areas for synchronization. At the strategic decision-making level, problems in the area of *design for synchronized cross-docking* include both local cross-dock and cross-docking network design aspects. Problems aimed at *synchronizing cross-docking operations* include a combination of tactical and operational problem aspects for the purpose of synchronizing network-wide and local cross-dock operations.

The practical relevance of synchronization in cross-docking networks, combined with a general lack thereof in existing literature, justifies future research in that regard. Details about the interdependencies between the cross-docking problem classes and insights required to identify and formulate cross-docking synchronization problems will be detailed in the subsequent sections.

Table 4.3: Classification of cross-docking research

	Network structure and facility types	Number of cross-docks	Location of cross-docks	Shape of the cross dock	Number of dock doors	Capacity of staging area	Design of staging area	Automation of material handling equipment	Capacity planning for network routes	Freight flow allocation	Shipment to destination assignment	Shipment dispatching	Collection and delivery vehicle routing	Dock door specification	Strip door assignment	Stack door assignment	Equipment and workforce capacity planning	Offline scheduling of inbound trailers	Online scheduling of inbound trailers	Offline scheduling of outbound trailers	Online scheduling of outbound trailers	Internal cross-dock workforce scheduling	Staging area utilization/shipment allocation	Shipment to outbound trailer assignment
Bartholdi and Gue (2004)	*	*	*	O	I	*	*	*	*	I	I	*	*	O	*	O	*	*	*	*	*	*	*	*
Carlo and Bozer (2011)	*	*	*	O	I	*	*	I	*	I	I	*	*	O	*	O	*	*	*	*	*	*	*	*
Vis and Roodbergen (2011)	*	*	*	I	*	I	O	I	*	I	I	*	*	*	*	*	*	*	*	*	*	*	O	*
Tsui and Chang (1990)	*	*	*	I	I	*	*	I	*	I	I	*	*	I	O	O	*	*	*	*	*	*	*	*
Tsui and Chang (1992)	*	*	*	I	I	*	*	I	*	I	I	*	*	I	O	O	*	*	*	*	*	*	*	*
Cohen and Keren (2009)	*	*	*	I	I	*	*	I	*	I	I	*	*	I	O	O	*	*	*	*	*	*	*	*
Stephan and Boysen (2011)	*	*	*	I	I	*	I	I	*	I	I	*	*	O	*	O	*	*	*	*	*	*	*	*
Oh et al. (2006)	*	*	*	I	I	*	*	I	*	I	I	*	*	I	*	O	*	*	*	*	*	*	*	*
Bartholdi and Gue (2000)	*	*	*	I	I	*	*	I	*	I	I	*	*	O	*	O	I	*	*	*	*	*	*	*
Gue (1999)	*	*	*	I	I	*	*	I	*	I	I	*	*	O	*	O	*	*	*	*	*	*	*	*
Bozer and Carlo (2008) - static	*	*	*	I	I	*	*	I	*	I	I	*	*	O	*	O	I	*	*	*	*	*	*	*
Bozer and Carlo (2008) - dynamic	*	*	*	I	I	*	*	I	*	I	I	*	*	O	O	O	I	*	*	*	*	*	*	*
Yu et al. (2008)	*	*	*	I	I	*	*	I	*	I	I	*	*	O	*	O	I	I	*	*	*	*	*	*
Chmielewski et al. (2009)	*	*	*	I	I	I	*	I	*	I	I	I	I	I	*	O	I	O	*	*	*	*	O	*
Luo and Noble (2012)	*	*	*	I	I	I	I	I	*	I	I	I	I	I	O	O	*	I	*	O	*	*	O	O
Arabani et al. (2010)	*	*	*	*	I	*	*	I	*	I	*	I	I	I	*	*	*	O	*	O	*	*	*	O
Arabani et al. (2011a)	*	*	*	*	I	*	*	I	*	I	*	I	I	I	*	*	*	O	*	O	*	*	*	O
Arabani et al. (2011b)	*	*	*	*	I	*	*	I	*	I	*	I	I	I	*	*	*	O	*	O	*	*	*	O
Arabani et al. (2012)	*	*	*	*	I	*	*	I	*	I	*	I	I	I	*	*	*	O	*	O	*	*	*	O
Boysen et al. (2010)	*	*	*	*	I	*	*	*	*	I	*	I	I	I	*	*	*	O	*	O	*	*	*	O
Forouharfard and Zandieh (2010)	*	*	*	*	I	*	*	*	*	I	*	I	I	I	*	*	*	O	*	O	*	*	*	O
Larbi et al. (2011)	*	*	*	*	I	*	*	*	*	I	I	I	I	I	*	*	*	O	*	O	*	*	*	O
Liao et al. (2012)	*	*	*	*	I	*	*	*	*	I	*	I	I	I	*	*	*	O	*	O	*	*	*	O
Vahdani and Zandieh (2010)	*	*	*	*	I	*	*	I	*	I	*	I	I	I	*	*	*	O	*	O	*	*	*	O
Yu and Egbelu (2008)	*	*	*	*	I	*	*	I	*	I	*	I	I	I	*	*	*	O	*	O	*	*	*	O
Vahdani et al. (2010)	*	*	*	*	I	Z	*	I	*	I	*	I	I	I	*	*	*	O	*	O	*	*	*	O
Soltani and Sadjadi (2010)	*	*	*	*	I	Z	*	I	*	I	*	I	I	I	*	*	*	O	*	O	*	*	*	O
Chen and Lee (2009)	*	*	*	*	I	*	*	*	*	I	I	I	I	I	*	*	*	O	*	O	*	*	*	I
Briskorn et al. (2010)	*	*	*	*	I	*	*	*	*	I	*	I	I	*	*	*	*	O	*	O	*	*	*	O
Alpan et al. (2011a)	*	*	*	*	I	*	*	*	*	I	I	I	I	I	*	*	*	*	I	O	*	*	*	O
Alpan et al. (2011b)	*	*	*	*	I	*	*	*	*	I	I	I	I	I	*	*	*	*	I	O	*	*	*	O
Boysen and Fliedner (2010)	*	*	*	I	I	*	*	*	*	I	I	I	I	I	*	*	*	O	*	I	*	*	*	I
Boysen et al. (2013)	*	*	*	I	I	*	*	*	*	I	I	I	I	I	*	*	*	O	*	I	*	*	*	I
Rosales et al. (2009)	*	*	*	I	I	*	*	I	*	I	I	I	I	I	*	*	I	O	*	I	*	*	*	I
Liao et al. (2013)	*	*	*	I	I	*	*	*	*	I	I	I	I	I	*	*	*	O	*	I	*	*	*	O
Acar et al. (2012)	*	*	*	*	I	*	*	*	*	*	*	I	I	I	*	*	*	O	*	*	*	*	*	*
Konur and Golias (2013a)	*	*	*	*	I	*	*	*	*	*	*	I	I	I	*	*	*	O	*	*	*	*	*	*
Konur and Golias (2013b)	*	*	*	*	I	*	*	*	*	*	*	I	I	I	*	*	*	O	*	*	*	*	*	*

McWilliams (2009b)	*	*	*	*	I	Z	*	I	*	I	I	I	I	I	*	I	I	O	*	*	*	*	*	*
McWilliams (2010)	*	*	*	*	I	Z	*	I	*	I	I	I	I	I	*	I	I	O	*	*	*	*	*	*
McWilliams et al. (2005)	*	*	*	*	I	Z	*	I	*	I	I	I	I	I	*	I	I	O	*	*	*	*	*	*
McWilliams et al. (2008)	*	*	*	*	I	Z	*	I	*	I	I	I	I	I	*	I	I	O	*	*	*	*	*	*
McWilliams and McBride (2012)	*	*	*	*	I	Z	*	I	*	I	I	I	I	I	*	I	I	O	*	*	*	*	*	*
McWilliams (2009a)	*	*	*	*	I	Z	*	I	*	I	I	I	I	I	*	I	I	*	O	*	*	*	*	O
Wang and Regan (2008)	*	*	*	I	I	*	*	I	*	I	I	I	I	I	*	I	*	*	O	*	*	*	*	O
Miao et al. (2009)	*	*	*	I	I	I	*	I	*	I	I	I	I	*	*	*	*	O	*	O	*	*	*	I
Chen and Song (2009)	*	*	*	*	I	*	*	*	*	I	I	I	I	I	*	*	*	O	*	O	*	*	*	I
Boysen (2010)	*	*	*	*	I	Z	*	*	*	I	I	I	I	I	*	*	*	O	*	O	*	*	*	I
Joo and Kim (2013)	*	*	*	*	I	*	*	*	*	I	*	I	I	I	*	*	*	O	*	O	*	*	*	O
Van Belle et al. (2013)	*	*	*	I	I	*	*	*	*	I	I	I	I	I	*	*	*	O	*	O	*	*	*	I
Shakeri et al. (2012)	*	*	*	I	I	*	I	I	*	I	I	I	I	*	*	*	I	O	*	O	*	I	O	I
Li et al. (2004)	*	*	*	*	I	*	*	I	*	I	I	I	I	I	*	*	I	I	*	I	*	O	*	I
Álvarez-Pérez et al. (2008)	*	*	*	*	I	*	*	I	*	I	I	I	I	I	*	*	I	I	*	I	*	O	*	I
Vis and Roodbergen (2008)	*	*	*	I	I	I	I	I	*	I	I	I	I	I	I	I	*	I	*	I	*	*	O	I
Bhaskaran (1992)	I	O	O	*	*	*	*	*	*	O	I	*	*	*	*	*	*	*	*	*	*	*	*	*
Sung and Song (2003)	I	O	O	*	*	*	*	*	O	O	I	*	*	*	*	*	*	*	*	*	*	*	*	*
Sung and Yang (2008)	I	O	O	*	*	*	*	*	O	O	I	*	*	*	*	*	*	*	*	*	*	*	*	*
Gümüs and Bookbinder (2004)	I	O	O	*	*	*	*	*	O	O	I	*	*	*	*	*	*	*	*	*	*	*	*	*
Mousavi and Moghaddam (2013)	I	O	O	*	*	*	*	*	*	O	*	*	O	*	*	*	*	*	*	*	*	*	*	*
Bachlaus et al. (2008)	I	O	O	*	*	*	*	*	*	O	O	*	*	*	*	*	*	*	*	*	*	*	*	*
Jayaraman and Ross (2003)	I	O	O	*	*	*	*	*	*	O	O	*	*	*	*	*	*	*	*	*	*	*	*	*
Ross and Jayaraman (2008)	I	O	O	*	*	*	*	*	*	O	O	*	*	*	*	*	*	*	*	*	*	*	*	*
Musa et al. (2010)	I	I	I	*	*	*	*	*	O	O	I	*	*	*	*	*	*	*	*	*	*	*	*	*
Lim et al. (2005)	I	I	I	*	*	I	*	*	I	O	O	O	*	*	*	*	*	*	*	*	*	*	*	*
Chen et al. (2006)	I	I	I	*	*	I	*	*	I	O	O	O	*	*	*	*	*	*	*	*	*	*	*	*
Ma et al. (2011)	I	I	I	*	*	*	*	*	I	O	O	O	*	*	*	*	*	*	*	*	*	*	*	*
Miao et al. (2012)	I	I	I	*	*	I	*	*	I	O	O	O	*	*	*	*	*	*	*	*	*	*	*	*
Marjani et al. (2012)	I	I	I	*	*	I	*	*	I	O	O	O	*	*	*	*	*	*	*	*	*	*	*	*
Erera et al. (2013)	I	I	I	*	*	I	*	*	O	I	I	O	*	*	*	*	*	*	*	*	*	*	*	*
Hernández et al. (2011)	I	I	I	*	*	*	*	*	I	I	I	O	*	*	*	*	*	*	*	*	*	*	*	*
Lee et al. (2006)	*	*	*	*	*	*	*	*	*	*	I	*	O	*	*	*	*	*	*	*	*	*	*	*
Liao et al. (2010)	*	*	*	*	*	*	*	*	*	*	I	*	O	*	*	*	*	*	*	*	*	*	*	*
Vahdani et al. (2012)	*	*	*	*	*	*	*	*	*	*	I	*	O	*	*	*	*	*	*	*	*	*	*	*
Santos et al. (2013)	*	*	*	*	*	*	*	*	*	*	I	*	O	*	*	*	*	*	*	*	*	*	*	*
Hu et al. (2013)	*	*	*	*	*	*	*	*	*	*	I	*	O	*	*	*	*	*	*	*	*	*	*	O
Wen et al. (2009)	*	*	*	*	*	*	*	*	*	*	I	*	O	*	*	*	*	*	*	*	*	*	*	O
Tarantilis (2012)	*	*	*	*	*	*	*	*	*	*	I	*	O	*	*	*	*	*	*	*	*	*	*	O
Section 4.6.1 (operational)	I	I	I	I	I	*	*	*	*	I	I	O	O	I	*	*	*	O	*	O	*	*	*	I
Section 4.6.2 (strategic-tactical)	I	I	I	O	O	*	*	*	O	O	I	*	*	O	O	O	*	*	*	*	*	*	*	*

4.5 The framework

Following from the results of Section 4.4, and based on our observations in practice, this section proposes the framework for synchronization in cross-docking networks. The framework is shown in Figure 4.4 and the interdependencies between the cross-docking problem classes are specified in Table 4.4. The interdependencies are identified by analyzing the cross-docking decision models proposed in literature, focusing on the inputs and outputs of the models in each problem class. Specifically, Table 4.4 lists the information needs for each cross-docking problem class considering the input parameters and constraints used in existing decision models.

The purpose of the framework and research classification is to support future cross-docking research in developing decision models for interrelated problem areas—and cross-docking synchronization problems in particular. The framework can be used to identify which interdependencies should be considered. When the relevant interdependencies are identified, the classification table points to related research, i.e., either addressing a similar decision problem or a problem that is related by means of a particular interdependency. Accordingly, values can be assigned to input parameters and constraints that realistically reflect the considered local cross-dock and network-wide problem context. Furthermore, the framework shows how future outputs of isolated cross-docking decision models can be characterized to be of value for solving decision problems from other cross-docking problem classes. Lastly, the outputs of a particular decision model can be validated against interdependent cross-docking decision problems.

The subsequent section will demonstrate how the proposed framework can be used to identify and formulate problems where multiple individual decision problems from network and local problem classes are considered simultaneously.

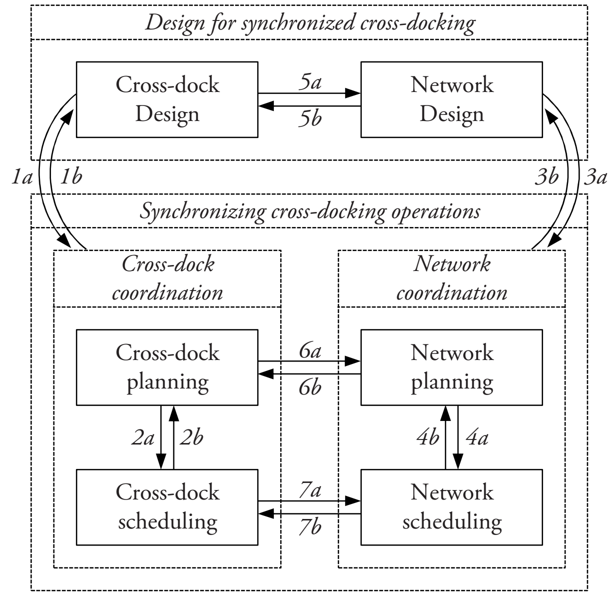

Figure 4.4: Framework for synchronization in cross-docking networks

Table 4.4: Interdependencies between cross-docking problem classes

Nr.	Interdependencies
1a	Relative dock door distances, internal cross-dock design
1b	Material handling/labor costs, scheduling/staging policies
2a	Dock door travel distances, available workforce
2b	Internal/truck scheduling or staging policies, trailer/shipment waiting times
3a	Costs for operating network-routes, freight flow constraints
3b	Freight flows and vehicles on network-routes, transportation and facility costs
4a	Available transport services, freight flows
4b	Time window constraints, trailer loading lists
5a	Fixed operating/establishing costs, cross-dock capacity
5b	Freight flow patterns, position/role in network
6a	Handling costs per shipment, cross-dock throughput rate
6b	Inbound trailer load characteristics
7a	Makespan, processing/waiting times, actual material handling/labor costs
7b	Trailer loading lists, trailer departure/arrival times

4.6 Illustrative cross-docking synchronization problems

This section presents two cross-docking synchronization problems, which are based on a recent distribution network re-design of an international grocery retailer. We do not claim that these two synchronization problems are the most important problems for future cross-docking research. Rather, the aim is to illustrate how the framework and research classification can be used to identify cross-docking synchronization issues from practice and translate them into scientifically relevant problems. Both illustrative problems are classified in Table 4.3.

Figure 4.5 depicts the retailer's distribution network, which is a *few-to-many* cross-docking network with a *single layer of cross-docks*. The network consists of two national distribution centers (NDCs), four regional distribution centers (RDCs), four cross-docks, and 950 retailers. The majority of stock keeping units (SKUs) are kept at the NDCs. There is no overlap in SKUs between the two NDCs. The remaining SKUs are kept at each of the RDCs. Hence, shipments to each retailer are assembled at both NDCs and one RDC and are consolidated at the cross-dock.

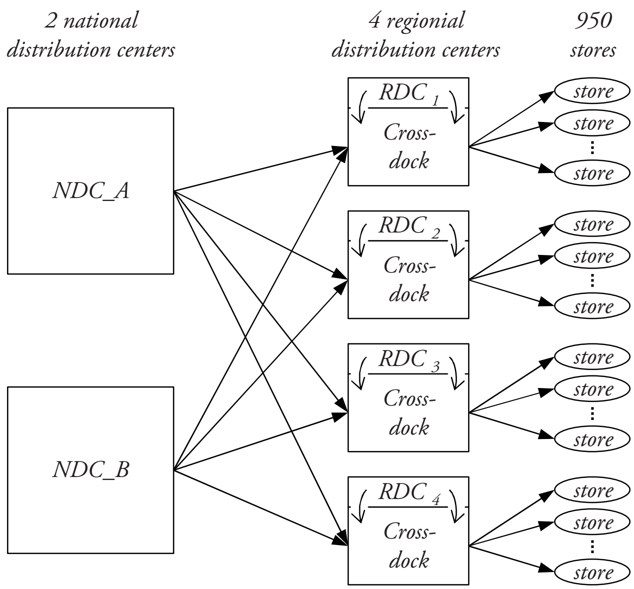

Figure 4.5: Schematic representation of the cross-docking network under study

The re-design of the distribution network entails shifting a large part of the SKUs from each RDC to the NDCs. As a result, the cross-docking flow through the network will increase considerably. Therefore, the current transportation planning and scheduling policies are reconsidered and potential changes to the cross-dock design and coordination are investigated. The prevalent interdependencies between the local cross-dock and cross-docking network decision problems in this context are described below, where we introduce two synchronization problems.

4.6.1 Tactical-strategic cross-docking synchronization problem

The first problem considers the design and layout of the cross-docks in synchronization with the interdependent network planning decisions (see Figure 4.6 for details). Decisions from the network design problem class are considered input to this problem and are therefore represented by a dashed box and line in the figure.

Network planning: Network planning in this context is concerned with assigning capacity to the network routes and allocating freight flows to those routes. At the tactical level, freight flow allocation decisions determine which retailers are served from which RDC. Solution approaches to this cross-docking network planning problem can be found in literature, see, e.g., Musa *et al.*, (2010) in Table 4.3.

Cross-dock design and planning: Determining which, and how many, of the dock doors at an RDC should be dedicated to serving the cross-docking freight flows is an important decision towards a potential re-design of the cross-docks. Cross-dock planning decisions are concerned with specifying those dock doors as either strip or stack door and allocating them to inbound and outbound trailers. In solving this hierarchical cross-dock design and planning problem, one can draw upon cross-dock design and dynamic dock door assignment approaches, see, e.g., Bartholdi and Gue (2004) and the dynamic model in Bozer and Carlo (2008) in Table 4.3.

Synchronization: Network planning decisions dictate the inbound and outbound freight flow patterns through the cross-docks, and hence strongly influence the optimal design and layout of those cross-docks. Similarly, optimal network planning is dependent on the design and layout of the cross-docks, which determine the throughput rate and actual costs associated with allocating shipments to a particular cross-dock. The corresponding synchronization problem is detailed in Figure 4.6. In this figure we specify the individual decision problems from multiple isolated problem classes and pinpoint the interdependencies between each class according to the framework.

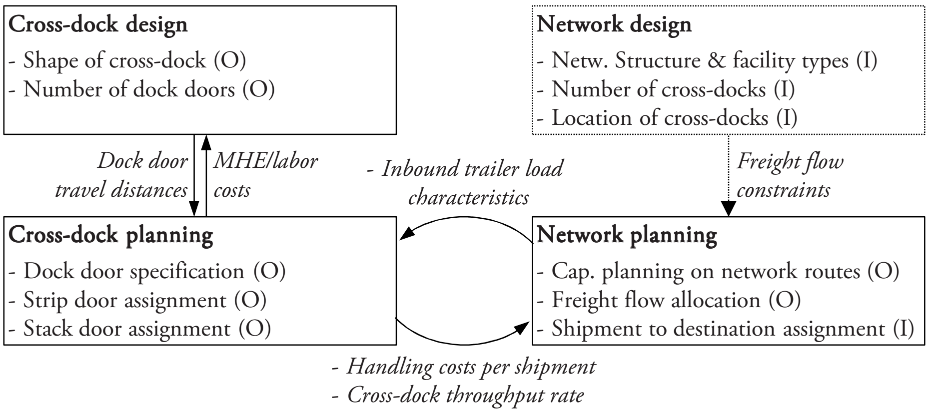

Figure 4.6: Tactical-strategic cross-docking synchronization problem

4.6.2 Operational cross-docking synchronization problem

The second problem considers a cross-docking synchronization problem at the operational level (see Figure 4.7 for details). Decisions from the network and local cross-dock design and planning problem classes are considered input to this problem and are therefore represented by a dashed box and line in the figure.

Network scheduling: At the inbound side of the cross-docks, i.e., the network routes connecting the NDCs to the cross-docks, network scheduling decisions are concerned with dispatching shipments to each trailer departing from the NDC. The departure times of the trailers are assumed known. Hence, network scheduling specifies which consolidated loads are assembled at the NDC and indicates the arrival times of these loads at the cross-dock. At the outbound side of the cross-docks, i.e., connecting each cross-dock to the retailers, network scheduling is concerned with determining the vehicle routes replenishing the retailers. These vehicle routes specify the loading lists and departure times of trailers leaving the cross-dock. For the first aspect of the network scheduling problem, one can draw upon approaches proposed in cross-docking literature, see, e.g., Erera *et al.* (2013) in Table 4.3; for the latter we refer to classic vehicle routing approaches (Eksioglu *et al.*, 2009).

Cross-dock scheduling: Cross-dock scheduling can address many internal operations. In this synchronization problem, we consider trailer scheduling alone in order to avoid excessive problem complexity. At the retailer's cross-docks, the outbound trailer departure times are known. The outbound trailer schedule thus boils down to the decision at which dock door each outbound trailer is served. We note that this problem is not equivalent to the classical dock door assignment problem since the number of outbound trailer far exceeds the number of stack doors. Solution approaches for the resulting inbound trailer schedule can be found in Boysen and Fliedner (2010) and Rosales *et al.* (2009)—as identified from Table 4.3. The solution approach most closely related to the overall trailer scheduling problem described above is found in Van Belle *et al.* (2013).

Synchronization: Whether the network and cross-dock schedules are appropriate, or even feasible, depends strongly on the outputs from one another. Differently consolidated inbound trailer loads affect the best possible trailer schedules in terms of material handling costs and waiting times. Moreover, trailer schedules are constrained by the deadlines and loading lists for outbound trailers—as imposed by the delivery vehicle routes. Network scheduling decisions benefit from information about the actual cross-dock processing times and operational costs associated with different shipment dispatching and vehicle routing policies. The corresponding synchronization problem is detailed in Figure 4.7.

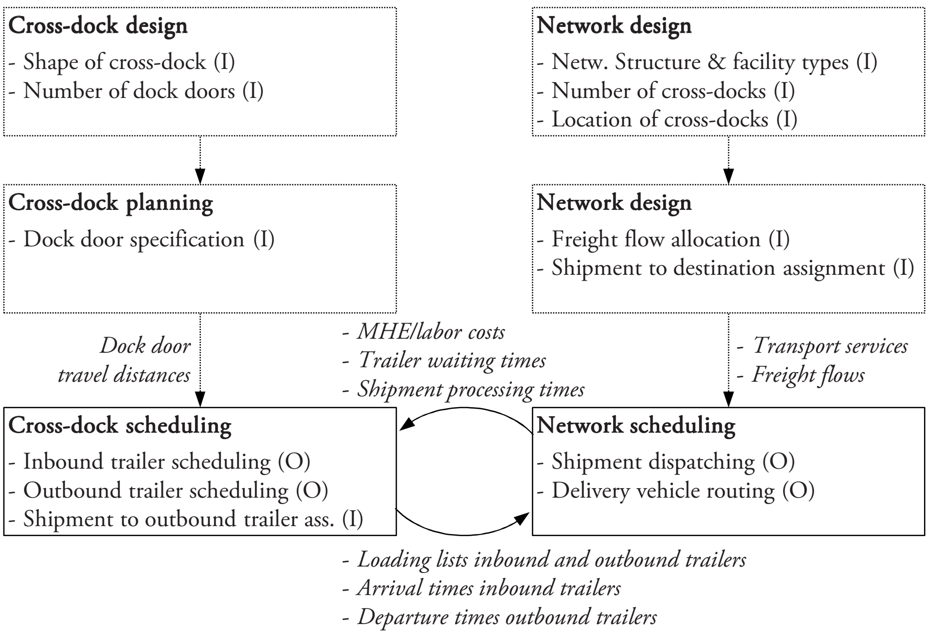

Figure 4.7: Operational cross-docking synchronization problem

4.6.3 Solution design methodologies

The two illustrative cross-docking synchronization problems pinpoint the interdependencies between individual decision problems from different problem classes. Several promising research opportunities reside in addressing these interdependencies. At a strategic or tactical decision-making level, it may suffice to focus on a local or network-wide decision problem. Nevertheless, studies with a local cross-dock focus should carefully consider cross-docking network characteristics. Similarly, network oriented cross-docking studies should consider local cross-dock characteristics in detail. This can be achieved through the identification of realistic input parameters from related problem classes, preferably followed by a sensitivity analysis of the most strongly interdependent decision problems. The framework presented in Section 4.5 can be used to identify relevant interdependencies.

As the research focus shifts towards the operational decision-making level, it becomes increasingly important to simultaneously consider local cross-dock and network wide logistics decision problems. To that end, future studies should aim to develop iterative solution approaches or—preferably—consider multiple local and network-wide decision problems in integration. We acknowledge that many challenging complexities may arise in such developments. For example, the integration of network-level shipment dispatching and local trailer scheduling decisions is hindered by frequent deviations from scheduled arrival times of inbound trailers due to uncertain traffic. Despite the potential complexities, solution approaches to isolated local cross-dock problems will at best result in local optima, which is paradoxical with the inherent network orientation of the cross-docking distribution strategy.

4.7 Conclusions

This chapter presents a research classification and framework for synchronization in cross-docking networks. The chapter asserts that the absence of a storage buffer inside a cross-dock translates into tightly coupled local and network-wide cross-docking operations. Nonetheless, the research classification shows that the overwhelming majority of papers have addressed isolated cross-docking problems. Accordingly, a framework is presented to support future research in developing decision models for cross-docking synchronization problems with practical and scientific relevance.

Existing cross-docking research is classified by means of a new general research classification scheme. The classification scheme is developed by identifying all individual cross-docking decision problems and structurally clustering them into six problem classes. The problem classes are distinguished based on their decision-making level (i.e., strategic, tactical, operational) and whether they address decision problems originating locally at the cross-dock or elsewhere in the cross-docking network. Our research classification resulted in an understanding about the information needs for, and outputs of, each problem class. The framework, specifying the interdependencies between the six cross-docking problem classes, is developed based on this understanding.

Lastly, this chapter shows how the proposed research classification and framework can be used to identify cross-docking synchronization problems, i.e., appreciating the interdependencies between local and network-wide cross-docking operations. In that regard, the classification table (Table 4.3) can be used to find solution approaches to related problem aspects. Moreover, the classification table supports the identification of promising research opportunities by showing combinations of cross-docking problem aspects that are not yet addressed in the literature. The framework shows the interdependencies that should be considered in order to take cross-docking synchronization aspects into account.

Chapter 5.

Exploring the interdependencies between local cross-dock and distribution network logistics

5.1 Introduction

Cross-docking is a logistics strategy that can reduce distribution costs and enhance the responsiveness of distribution systems. It enables the consolidation of products from multiple origins into full truckloads, which are then send to a *cross-dock* facility where they are unloaded and immediately recombined with products sharing the same destination (Bozer and Carlo, 2008). Dating back to the 1990s, cross-docking has been applied in a range of industrial settings—predominantly in parcel delivery (Forger, 1995), less-than-truckload trucking (Gue, 1999), car manufacturing (Witt, 1998), and retailing (Stalk *et al.*, 1992). Industry-wide interest in cross-docking is confirmed by two recent surveys (Saddle Creek Logistics Services 2008; 2011). Following its sustained popularity in industry, cross-docking has become a prominent subject of interest in academic literature. A comprehensive overview of cross-docking literature is presented in Chapter 4.

Being a just-in-time logistics strategy (Gue, 2007), the success of cross-docking is largely determined by the extent to which storage buffers can be eliminated from the intermediary logistics facilities in the distribution network. In the more traditional warehousing strategy, storage buffers are used to realize economies in transportation costs. Products are retrieved from storage at the warehouse upon customer order and assembled into consolidated truckloads. Storage is efficiently replenished by operating fully loaded trucks between the suppliers and the warehouse. The storage buffer at the warehouse, effectively, decouples the planning and execution of inbound logistics operations from the local warehouse and outbound logistics operations. Cross-docking fundamentally differs from warehousing in that regard. Inside the cross-dock, products are either moved directly from inbound to outbound trailers or temporarily placed on the ground. The absence of storage buffers results in strong interdependencies between local cross-dock operations and the inbound and outbound logistics operations (Vogt, 2010). For example, a change in the composition and/or arrival time of inbound trailer loads at the cross-dock directly affects the time, material handling, and space required to assemble outbound loads.

Surprisingly, few academic cross-docking papers recognized these interdependencies. Vogt (2010) concludes that prior work has seldom considered cross-docking as a distribution network strategy. Rather, it has focused predominantly on optimizing local cross-dock operations, while little attention is given to the distribution network in which the cross-dock operates. The research classification in Chapter 4 supports this conclusion and complements it with the remark that prior studies that do address cross-docking network optimization have not considered operations at the cross-dock in detail. The need for a network orientation in cross-docking management—considering local and network-wide cross-docking operations simultaneously—is based upon the premise that the absence of storage buffers at a cross-dock results in strong interdependencies with its inbound and outbound logistics operations. Thus far, cross-docking literature has supported this premise by logical arguments and anecdotal evidence alone.

The purpose of this study is to address this gap in literature and provide empirical evidence for the need to address the interdependencies between local and network-wide cross-docking operations. Moreover, the aim is to better understand these interdependencies and explore how they can be addressed in future cross-docking research and practice. To this end, we adopted a simulation research approach, modeling the cross-docking operations of a large international grocery retailer. The model reflects the current design and control of the retailer's operations at the cross-dock as well as its inbound and outbound logistics activities. In addition, we propose a new planning policy for local cross-dock operations and simulate its effects on a range of cross-docking performance indicators. The same indicators are used to evaluate the performance effects of a proposed change in the inbound logistics activities. For each of the proposed changes, we carefully consider local cross-dock and network-wide logistics operations.

The chapter is organized as follows. First, Section 5.2 briefly introduces the range of cross-docking management decisions and details our research motivation based on prior work. Subsequently, Section 5.3 presents the research objectives and justifies the use of simulation to attain those objectives. The chapter continues with a detailed description of the case and conceptual model underpinning the simulation in Section 5.4. Descriptions of the simulation model, experimental factors, and performance measures are provided in the Section 5.5, and are followed by the simulation results in Section 5.6. Section 5.7 outlines the practical and theoretical implications from this study. The chapter is concluded in Section 5.8.

5.2 Background

This section first introduces the main cross-docking management decisions and then presents our research motivation based on a discussion of prior cross-docking studies.

5.2.1 Cross-docking management decisions

Logistics managers responsible for the design and control of cross-docking operations face a range of decision problems. Below, we briefly introduce these problems and make reference to the main solution approaches proposed in literature. According to Chapter 4, cross-docking solution approaches can be classified based on the decision-making level of the problem at hand (i.e., strategic, tactical, or operational) and based on whether the problem occurs at the local cross-dock level or at the network level. For a comprehensive overview of cross-docking decision problems and existing solution approaches, the reader is referred to Chapter 4, where the main cross-docking management decisions are summarized in Table 4.2.

Cross-docking papers that consider a problem at a network level mostly address strategic network design decisions, i.e., determining the optimal number and locations of cross-docks in the distribution network (e.g., Gümüs and Bookbinder, 2004). Solution approaches to this decision problem also consider the strongly related tactical decision specifying the transport capacity on network routes. These network design approaches assume the network structure and facility type definitions to be known. A facility type definition describes, for each type, e.g., the fixed costs to operate the facility, the maximum capacity, and the distribution functions performed. At the tactical and operational decision-making level, cross-docking network decisions include the allocation of freight flows to the facilities in the distribution network (e.g., Musa *et al.*, 2010), dispatching shipments onto scheduled transport services (e.g., Hernández *et al.*, 2011) and constructing vehicle routes from and to the cross-dock (e.g., Liao *et al.*, 2010).

The majority of cross-docking papers consider a problem that occurs locally at the cross-dock. A few of those studies propose solution approaches for the design of cross-docks, e.g., the optimal size and shape for a cross-dock (Bartholdi and Gue, 2004; Carlo and Bozer, 2011). Although cross-docks hold no long-term storage, they often consist of an area where products can be sorted and temporarily placed on the ground to facilitate consolidation activities. Vis and Roodbergen (2011) propose a policy for the design of this area, which is, which is referred to as a *staging area*. The allocation of dock doors to inbound and/or outbound trailers is the local cross-dock decision most frequently addressed. Papers addressing this problem can be separated in two groups. The first group considers the allocation of dock doors at a tactical decision-making level and is referred to as *dock door assignment* literature (e.g., Bartholdi and Gue, 2000; Bozer and Carlo, 2008; Gue, 1999; Tsui and Chang, 1990; 1992). These studies are based on the premise that determining *where* (i.e., at which dock door) trailers are served can improve local cross-dock operations by reducing the inner travel distance of material handling equipment. The second group considers the problem at an operational level. This group is referred to as *truck scheduling* literature and focuses primarily on *when* (i.e., in which sequence) trailers are served at the cross-dock. Truck scheduling approaches are based on the premise that an efficient allocation of dock doors to trailers can synchronize unloading and loading activities to realize a smooth flow of products between inbound and outbound doors (Boysen and Fliedner, 2010). Other local cross-dock problems, such as workforce planning and material handling system design, received little or no research attention.

5.2.2 Research motivation

The motivation for this research stems primarily from the lack of consideration for the potential interdependencies between local cross-dock and network-wide logistics operations in prior work. Generally, existing optimization approaches either address decision problems at the network level or at the local cross-dock level.

Optimization approaches for network-wide logistics operations in distribution networks with cross-docks seldom consider local cross-dock operations. Notable exceptions in that regard have revealed interdependencies between local cross-dock and network level performance. Yan and Tang (2009) and Tang and Yan (2010) present mathematical models supporting logistics managers in the strategic decision where to label products, i.e., at the cross-dock or upstream in the distribution network. The labeling activity marks the point at which interchangeable products are allocated to a specific customer, and hence are no longer interchangeable. Labelling at the cross-dock is advantageous at a network level as the postponed allocation of products to customers enhances the ability to respond to last-minute changes in customer demand. This network-benefit results in increased operational costs at the cross-dock, however. To our knowledge, other interdependencies are not mentioned in cross-docking literature. In this chapter, we consider both local and network-wide cross-docking operations to ensure that any network level improvement does not come at the expense of local cross-dock performance—and vice versa.

Local cross-dock optimization approaches often lack a thorough empirical validation for the distribution network setting they consider. Due to the absence of storage buffers, cross-dock operations in practice are heavily constrained by the network level decisions dictating the inbound and outbound logistics operations. In retailing, for example, cross-dock operations are faced with fixed outbound trailer departure times in order to ensure on-time deliveries to the retail stores. The lack of consideration for the distribution network setting in existing local cross-dock optimization approaches has resulted in many cross-dock planning and scheduling policies that violate prevalent network level constraints. Furthermore, no local cross-dock optimization studies have considered potential ways in which changes in the design and control of the distribution network can improve operational performance at the cross-dock. As a consequence, several easily obtainable local performance improvements may have not yet been identified. This chapter does consider potential changes in distribution network design and control to improve cross-docking performance. Moreover, we specify prevalent network level constraints on local cross-dock operations in a retail distribution context and develop a local cross-dock planning policy that satisfies these constraints.

Deriving understanding about the interdependencies between local cross-dock and network-wide logistics operations requires a careful analysis of overall cross-docking performance. We note that prior cross-docking studies often used a single performance measure to demonstrate the value of the proposed solution approach. Network level solution approaches typically aim to meet transportation demand at the lowest possible costs, e.g., operational facility and transportation costs. Recent classifications of cross-docking literature (Boysen and Fliedner, 2010; Van Belle *et al.*, 2012) show that truck scheduling approaches have been primarily evaluated by measuring the makespan of the operations at the cross-dock, i.e., the timespan between the first unloaded and last loaded shipment. Papers presenting dock door assignment policies measured cross-dock performance improvements considering material handling efficiency, often using the internal travel distance of material handling equipment as a proxy. In this chapter, we adopt a more holistic view on cross-docking performance by adopting a wide-range of performance indicators.

5.3 Methodology

Owing to the above limitations in literature, the following research objectives are formulated:

> ***RO1***: *Identify and explain the network level constraints imposed on local cross-dock operations in a retail distribution context and illustrate how they can be addressed during the development of a local cross-dock planning policy.*
>
> ***RO2***: *Explore how the design and control of the distribution network can be adjusted to improve overall cross-docking performance.*
>
> ***RO3***: *Explore how often-used individual cross-docking performance indicators can be put into a more holistic performance context.*

We adopted a simulation research approach to attain the above objectives. Robinson (2004) defines simulation as the *"experimentation with a simplified imitation (on a computer) of an operations system as it progresses through time, for the purpose of better understanding and/or improving that system."* In this chapter, simulation is used to understand and improve the cross-docking operations in the distribution network of a retailer. The cross-dock facility forms a natural focal point of study as the basic cross-docking operations are performed at that facility. Nonetheless, a systems perspective is required due to the tight coupling between the local cross-dock operations and the logistics activities elsewhere in the distribution network (Vogt, 2010). Simulation is a research method that is particularly well-suited to represent the variability, interconnectedness and complexity often encountered in such systems (Evers and Wan, 2012; Law and Kelton, 2000; Robinson, 2004). Accordingly, several previous cross-docking studies have used simulation methods (e.g., McWilliams *et al.*, 2005; Wang and Regan, 2008; Yang *et al.*, 2010).

The model developed in this study simulates the cross-docking operations in the distribution network of a large international grocery retailer—henceforth referred to as "*retailer*". The retailer is considered to be leading with regard to the design and control of its distribution network, in which the broad implementation of cross-docking plays an important role. During the research project, the retailer facilitated many interviews and observation sessions and allowed unrestricted access to operational data and archival documents. Accordingly, our case selection can be justified by the unique research opportunity it provided (Eisenhardt and Graebner, 2007; Yin, 1994) to identify, investigate, and describe examples illustrating the interdependencies between the local cross-dock operations and its inbound and outbound logistics operations. A detailed description of the case is provided in the subsequent section, which also elaborates how the case is represented in a conceptual model underpinning the simulation design (Robinson, 2004). Section 5.5 provides details regarding the actual simulation model.

The validity of the simulation design is determined by assessing the *face validity* and *experiment validity* and by performing *white-box* and *black-box* tests. To this end, we visited several logistics facilities throughout the distribution network and conducted interviews with employees and managers that play a key role in the cross-docking operations—with due attention being given to triangulation with the collected quantitative data. In total, we logged 110 hours of observations and performed 11 interviews (which lasted between 1 and 2 hours each). Face validity is assessed through interviews discussing the scope, level of detail, and correctness of the conceptual model. In order to ensure input data validity, all datasets were retrieved directly from the responsible department and were checked for inconsistencies. Experiment validity is addressed by applying the confidence interval method to determine the appropriate run-length and number of runs for each experiment (Robinson, 2004). Black-box testing involved a comparison of the simulated cross-dock operations and the real-world operational data retrieved from the warehouse management system. White-box testing was performed through validation sessions with employees and managers that are daily involved with the cross-docking operations, e.g., cockpit-operator, team-leaders, and cross-dock site manager.

Considering the research objectives of this study, the use of simulation has two advantages. Firstly, it allows testing multiple complex scenarios without interfering with on-going operations. Secondly, simulation enables the monitoring of many performance indicators over time and therefore enables the measurement of cross-docking performance in a holistic way. The main shortcomings of simulation reside in its inability to solve problems to optimality and the limited generalizability of research findings (Evers and Wan, 2012). In addition, the generalizability of our findings is limited by the use of a single case. While acknowledging this limitation, we believe that the results of our study provide sufficient exploratory evidence in generating insights that should be applicable to other cross-docking settings as well, particularly in retail cross-docking.

5.4 Case and conceptual model

This section describes the current situation at the case and presents the conceptual model explaining which aspects of the real-world situation are modeled and at what level of detail. As recommended in Robinson (2004), the conceptual model is represented by means of component lists and a logic flow diagram. We first describe the case and conceptual model at the distribution network level and then at the local cross-dock level.

5.4.1 Distribution network level

We study the cross-docking operations in the retailer's fresh food distribution network in The Netherlands. The distribution network design is schematically depicted in Figure 5.1—and is common for retailers in Europe (Bourlakis and Bourlakis, 1999). Each of the 950 retail stores is allocated to one of four regional distribution centers (RDCs), roughly dividing the stores into equally-sized groups. The regional distribution centers hold a storage facility for fast-moving bulk products. Slow moving products and highly perishable products are stored at one of two national distribution centers (NDCs). Storage is replenished by 80-120 suppliers. The stock keeping units (SKUs) are separated in three disjoint sets across NDC_A, NDC_B, and the RDCs such that most suppliers either replenish a single NDC or all RDCs. For the purpose of readability, Figure 5.1 does not display all the freight flows replenishing the RDCs. $RDC_{2,3,4}$ are replenished in a similar fashion to RDC_1.

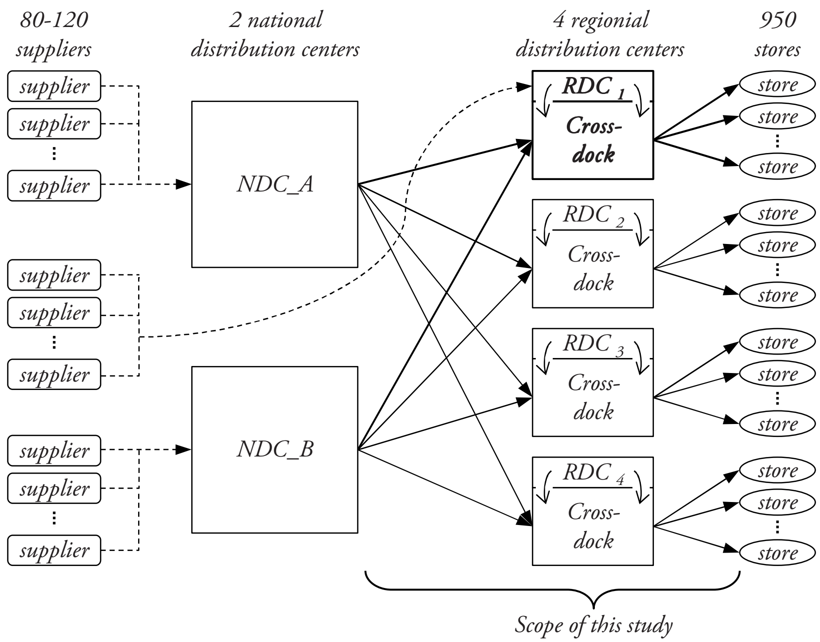

Figure 5.1: The retailer's fresh food distribution network in The Netherlands

Figure 5.1 specifies the scope of the conceptual model considered in this research. In order to limit the breadth of the model, the suppliers and retail stores are not considered. Moreover, the warehousing functions inside the RDCs (e.g., storage and order-picking) as well as the freight flows replenishing those warehouses are excluded. The model does include the freight flows from the NDCs to RDC_1 and the cross-docking operations performed inside RDC_1. Products are delivered to the stores by means of consolidated truckloads that are assembled at a dedicated cross-docking area at the RDCs, which is referred to as the *cross-dock*. A store delivery always comprises SKUs from both NDCs and one RDC. Products are retrieved from storage upon ordering and placed onto homogeneously sized load-carriers. Load-carriers bound for different store deliveries are assembled at each NDC for transportation in full truckloads to the cross-dock, where they are unloaded and immediately recombined with load carriers sharing the same store delivery.

The planning of network level logistics operations is performed by a central planning department. This department sets time windows for, and determines the load composition of, the trailers transporting load-carriers between each RDC and its allocated retail stores. The planning is characterized by a medium-term horizon (i.e., 3 months) and considers service level agreements and norm volumes for retail store demand. Service level agreements are represented by store delivery moments ensuring that each store receives its ordered products within an agreed timespan from ordering. The norm volumes specify the expected demand associated with each store delivery moment and is based on extensive historical data. Around 65% of the trailers departing the cross-dock contain load-carriers for two stores; 35% of the trailers contain load-carriers for a single store—as is shown in Figure 5.2 for RDC_1.

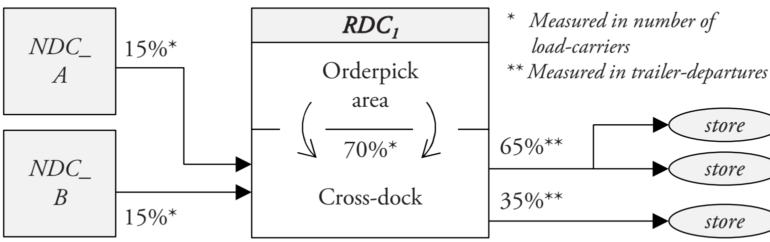

Figure 5.2: Freight flows through the cross-dock

The planning of downstream transport routes between the RDCs and retail stores dictates the planning of the upstream transportation between the NDCs and RDCs. Figure 5.2 shows that around 70% of the load-carriers for each store delivery originate from stock at the RDC. These load-carriers are picked from storage inside the RDC upon store order and placed at their corresponding outbound staging area. The remaining 30% of the load-carriers originates at one of the NDCs, i.e., roughly 15% from each NDC. Trailers from the NDCs always contain load-carriers destined for the first departing trailers at the RDC. The central planning department considers the following time window for determining the arrival times of trailers at the cross-docks:

- The *latest possible arrival time* of a trailer at the cross-dock is given by the most proximate departure time of the load-carriers inside that trailer minus a fixed time for performing local cross-dock operations. A time buffer is added to avoid load-carriers missing their outbound trailer departure.
- The *earliest possible arrival time* of a trailer at the cross-dock is given by the latest opening time of the outbound staging areas for any of its load-carriers. An arrival before then would result in unmoveable load-carriers (i.e., their staging area has not opened yet) and necessitates undesired temporary storage at the inbound unloading area.

In principle, a trailer's arrival at the cross-dock is scheduled as the latest possible arrival time. If the earliest possible arrival time surpasses the latest possible arrival time, however, the earliest possible trailer arrival time is taken.

The central planning department monitors the transport operations in real-time against the medium-term plan. Actual store orders may deviate from norm volumes, which may cause outbound trailer loads exceeding the maximum trailer capacity. We note that substantial safety margins are considered during the planning of store delivery routes. The purpose of these safety margins is to enhance robustness of the plan against regular fluctuation in retail store demand, i.e., avoid the need for major changes to on-going operations. Occasionally, actual store demand or considerable transport delays require a change in plan or the use of a courier service to transport excess load-carriers. In general, the retailer's network control is a fuzzy process that seldom leads to deviations from plan in terms of adding or deducing trailers for the outbound transportation routes.

Table 5.1 shows how the real-world components at the distribution network level are incorporated in our conceptual model.

Table 5.1: Conceptual model – component list at the distribution network level

Component	Level of detail	Include/exclude	Comment
Store demand volumes	Demand volume for SKUs at NDCs	Include	SKUs that are located at the NDCs are order-picked at the NDC and cross-docked at the RDC. The corresponding freight flow is the main focus of this study.
	Demand volume for SKUs at RDC	Exclude	The corresponding freight flow interferes little with the cross-docking flow. Excluded to limit model complexity (i.e., particularly its breadth).
	Demand fluctuation	Include	Demand fluctuation for each store is assumed proportional with the normally distributed total demand volume.
	Load-carrier level	Include	Retail store demand is considered at the load-carrier level, i.e., aggregated from SKUs. The load-carrier is the lowest level of granularity for the cross-docking operations. Each load-carrier has a specific origin (NDC), destination (store) and due date (i.e., departure time from the cross-dock).
	SKU level	Exclude	SKU level is only important for order-picking, which is outside the scope of research.
Outbound trailer schedule	Departure times	Include	Considered as input to the model. This is justified by the fact that virtually all outbound trailers depart the cross-dock on-time.
	Load composition	Include	Store delivery routes are obtained from retailer and considered as input. The actual load compositions depend on the fluctuating store demands.
	Arrangement of load	Exclude	The arrangement of load-carriers inside outbound trailers is not considered.
	Outbound trailer capacity	Exclude	Outbound trailer capacity issues are rare and dealt with by network control, which is outside the research scope.
Inbound trailer schedule	Arrival times	Include	Arrival times are scheduled according to real-world planning logic and added with a stochastic “delay” (normal distribution, mean 5 minutes, standard deviation 17 minutes).
	Load composition	Include	Load composition is set according to real-world planning logic
	Inbound trailer capacity	Include	Used as a constraint for determining the load composition.
	Arrangement of load	Include	***Experimental factor*** – discussed in subsequent section.

The conceptual model exactly follows the retailer's planning logic for the inbound and outbound processes. The retailer provided us with 40 weeks of operational data from which we selected one representative planning horizon. The data includes actual store delivery routes (i.e., from RDC_1 to the stores) for the complete planning horizon. The corresponding outbound trailer schedule is extracted and used as input to our model. Furthermore, the data includes store demand volumes. We considered only store demand volumes that result in a cross-docking freight flow, i.e., load-carriers that are moved from an NDC, through the cross-dock, to the stores. The total demand volume fits a normal distribution (Anderson-Darlings test of normality, at $p > 0.05$). We used this distribution for store demand volume as input to our model so that any number of experiments can be ran. We generated the inbound trailer schedules (i.e., from NDC_A and NDC_B to RDC_1) using a sample from the normally distributed store demand volumes and according to the retailer's actual planning logic. Network control is not considered in our conceptual model.

5.4.2 Local cross-dock level

Figure 5.3 illustrates the cross-dock layout at RDC_1.

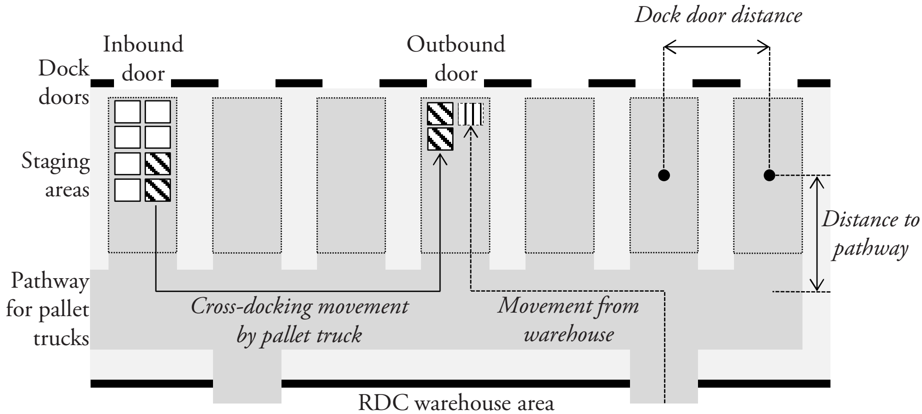

Figure 5.3: Layout of RDC_1

In reality, the cross-dock has 31 dock doors, which are all positioned along one side of RDC_1. There is a staging area behind each dock door. When used as inbound door, the staging area serves as a buffer to unload all inbound load-carriers before they are moved through the cross-dock. When used as outbound door, the staging area serves as a buffer to temporarily keep load-carriers while the consolidated outbound trailer load is fully assembled. Staging areas are connected by a pathway for electric pallet trucks with a rider platform (hereafter simply referred to as *pallet trucks*). Each staging area has a particular position in the cross-dock. Figure 5.3 shows how we modeled the distance between two staging areas. This distance is set as the variable distance between the centers of the corresponding dock doors and two times the fixed distance to the pathway.

The load-carriers from both NDCs are cross-docked from inbound to outbound dock doors. Upon arrival at the cross-dock, an inbound trailer is assigned to a dock door and immediately unloaded when docked. The truck driver moves the load-carriers from the trailer through the dock door, where a team of material handlers takes over to scan in the load-carriers and place them into the staging area. Currently, the load-carriers inside inbound trailers are arranged randomly. Therefore, the material handlers cluster load-carriers according to the store number on their shipping label during the unloading process. When the unloading of a trailer and the clustering activities are completed, the Warehouse Management System (WMS) is used to check the completeness of the inbound trailer load and then generates movement orders.

A homogeneous set of three pallet trucks is dedicated to performing cross-docking movements, i.e., move load-carriers from inbound to outbound dock doors. A pallet truck has the capacity to move a batch of 4 load-carriers in one movement. If a cluster of load-carriers exceeds 4 load-carriers, multiple movement orders are generated—always loading the pallet truck as much as possible. A movement can only be performed when the outbound staging area is open, i.e., when all load-carriers for the previous trailer at that door have been loaded. The material handler requires some time to prepare the batch of load-carriers for pickup by the pallet truck. Since the pallet trucks require considerable maneuvering space when picking up the load-carriers, the material handlers always select the cluster of load-carriers that is located closest to the pathway. When the material handler has reached the outbound staging area, the load-carriers are removed from the pallet truck. Similar to the unloading of trailers, loading is performed by the truck driver and a dedicated team of material handlers.

Orders to pick products from the RDC warehouse are released according to the outbound trailer schedule. There are dedicated resources available to fulfil the corresponding material handling activities, i.e., for order-picking and delivering the load-carriers to their corresponding outbound staging area.

Table 5.2 shows how the real-world components at the local cross-dock level are incorporated in our conceptual model. The corresponding logic flow diagram is displayed in Figure 5.4. In line with the scope at a distribution network level, all material handling activities related to the warehousing functions inside the RDC are not considered. The conceptual model includes the material handling operations performed to unload (and cluster) incoming load-carriers from inbound trailers, move load-carriers to their corresponding outbound dock doors and load them onto the outbound trailers.

Table 5.2: Conceptual model – component list at the local cross-dock level

Component	Level of detail	Include/exclude	Comment
Dock door	Availability	Include	Each dock door is modelled as a parallel inbound and outbound door resource – hence, when an outbound trailer occupies a door, the processing of an arriving inbound trailer can immediately start. Due to the cyclic dock door assignment logic, it is not possible for two outbound trailers to be docked simultaneously at the same door.
	Assignment	Include	***Experimental factor*** – discussed in subsequent section.
Staging area	Utilization	Include	The staging area is modeled as a single-dimensional buffer (i.e., queue) in which load-carriers can be placed.
	Load-carrier location	Exclude	The exact (two-dimensional) location of load-carriers in a staging area is not considered.
	Position of areas inside cross-dock	Include	The relative distance between staging areas in the cross-dock is modeled according to Figure 5.3 and input to the model as a dock door *distance matrix*.
	Opening time	Include	Set by the outbound trailer schedule, i.e., the departure time of the previous trailer at the staging area's dock door.
	Closing time	Include	Set by the outbound trailer schedule, i.e., the departure time of the current trailer minus loading time and buffer.

Table 5.2: Continued

Component	Level of detail	Include/exclude	Comment
Unload material	Unloading time	Include	Modeled as a constant for each load-carrier (9 seconds) based on observatory measurements.
handling team	Clustering time	Include	Incurred when inbound loads are randomly organized. Modeled as a constant for each load-carrier (8 seconds) based on observatory measurements.
	Material handlers allocation	Exclude	Assumed always available when needed. Justified by the existence of a dedicated team supporting the truck driver in unloading an inbound trailer and clustering the inbound load-carriers.
Cross-docking movement material handling team	Pallet truck allocation	Include	A pallet truck becomes available at the moment its current movement is finished, i.e., load-carriers are dropped-off at the outbound staging area.
	Pickup time	Include	Modeled as a uniform distribution (min 30, max 50 sec.). Variation caused by preparation of a batch of load-carriers.
	Drop-off time	Include	Modeled as uniform distribution (min 15, max 25 sec.)
	Movement speed	Include	Modeled as a constant speed of 1.5 m/s, as derived from WMS-data. This speed includes a compensation for congestion – the actual cruising speed is 2.3 m/s.
	Moving distance	Include	Variable according to distance between the corresponding inbound and outbound staging areas.
Load material handling team	Loading time	Include	The loading time for each outbound trailer is input to the model. It is derived from operational data set.
	Material handlers allocation	Exclude	There is a dedicated team of material handlers supporting the truck driver in loading an outbound trailer
Warehousing material handlers	Order-picking	Exclude	Considered outside the scope.
	Moving RDC load-carriers to staging area	Exclude	Considered outside the scope. Interference between RDC movements and cross-docking movements are addressed in moving speed.

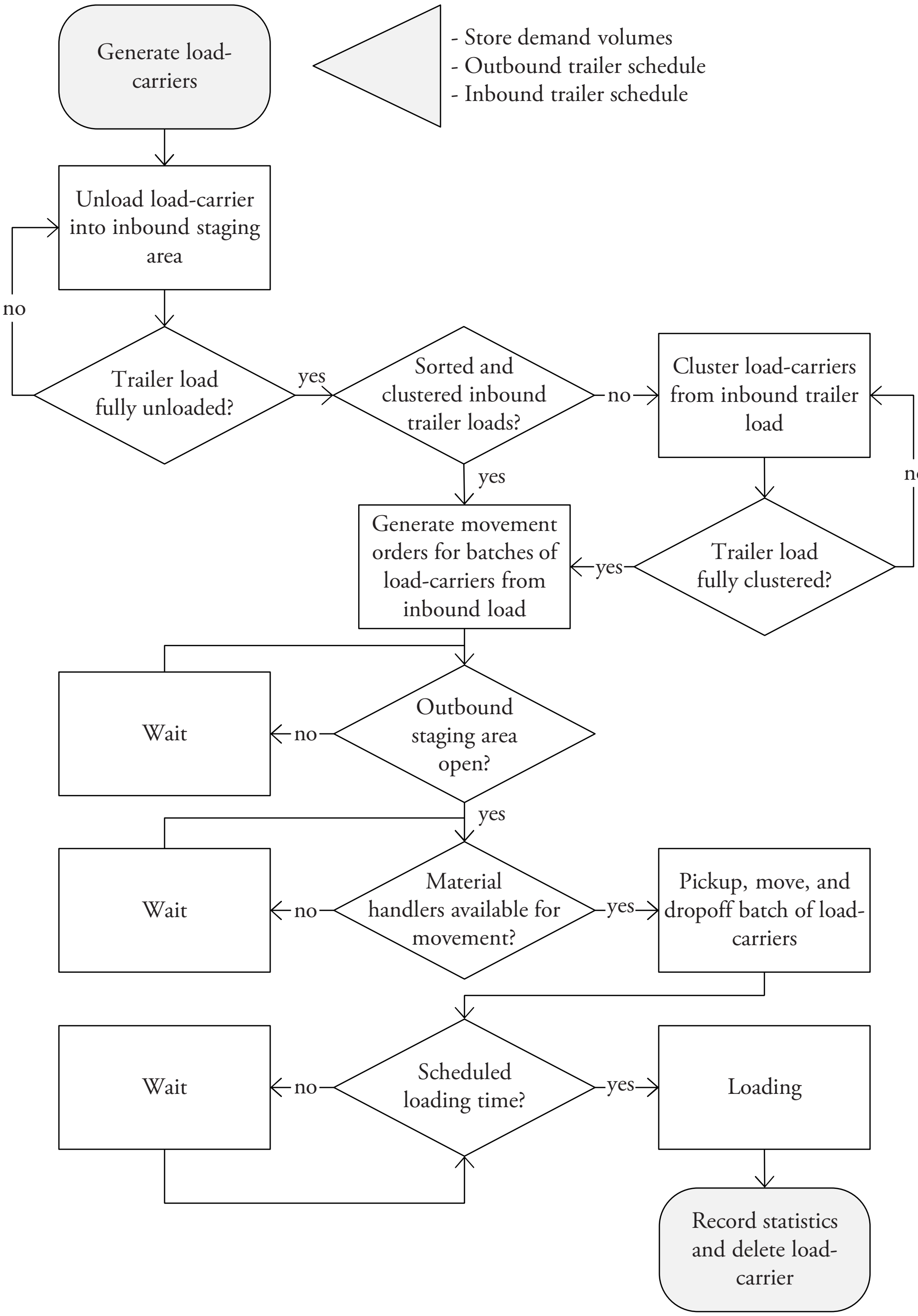

Figure 5.4: Conceptual model – logic flow diagram at the local cross-dock level

Lastly, this section discusses the policy currently in place to assign dock doors to inbound and outbound trailers at the cross-dock. Five dock doors in the middle of cross-dock are used to serve inbound trailers. Upon arrival, an inbound trailer is arbitrarily assigned to any available inbound door. The other twenty-six dock doors serve outbound trailers. All outbound trailers within a single planning horizon are sorted according to their given departure time. Starting at the first dock door, each succeeding door is allocated to the next departing outbound trailer. Since there are more outbound trailers than dock doors, the dock door assignment results in multiple operational cycles. Only after an outbound trailer at a particular dock door is fully loaded, the corresponding outbound staging area can be used to assemble the load for the next outbound trailer departing that dock door. The time available for assembling outbound loads is thus specified by the inter-departure time of outbound trailers. The current dock door assignment policy is displayed in Figure 5.5. The figure also illustrates the rationale behind the inbound trailer arrival time window considered during network level planning.

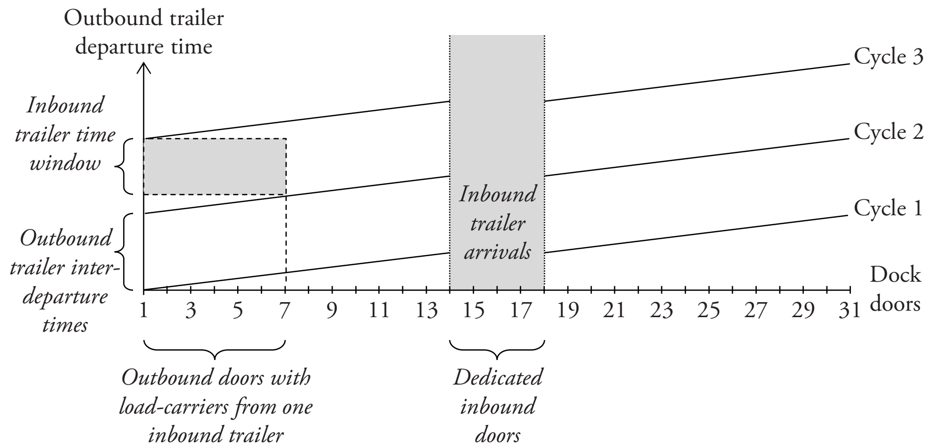

Figure 5.5: The current dock door assignment policy

5.5 Simulation design

The simulation design is discussed by describing the experimental factors, simulation model, and performance measures.

5.5.1 Experimental factors

This study includes two experimental factors to derive practical and theoretical insights about the interdependencies between local and network-wide cross-docking operations.

New dock door assignment policy

The first experimental factor entails a proposed change to the current dock door assignment policy. We note that any dock door assignment policy in our research setting is constrained by the inbound trailer arrival times and outbound trailer departure times imposed by the distribution network level planning decisions. Accordingly, academic literature was studied to identify a policy that dynamically assigns dock doors to trailers (i.e., assigning each dock door to multiple distinct trailers over the length of a single planning horizon) under given trailer arrival and departure time windows. To our knowledge, no existing dock door assignment or truck scheduling approach fully complies with these constraints. In short, dock door assignment models do not consider serving multiple trailers at a single dock door. Existing truck scheduling models assume that trailer arrival and/or departure times (and the corresponding freight flows through the distribution network) can be determined based on cross-dock operational preferences alone.

Since no directly applicable dock door assignment policy was identified in literature, this chapter proposes a new policy. Figure 5.6 displays our new policy, which aims to reduce the internal travel distance of load-carriers from inbound to outbound doors. As it was not our primary research objective to develop a sophisticated mathematical model, we introduce the new dock door assignment policy in a few simple steps:

- The *initial assignment of outbound trailers* is similar to the current assignment policy, i.e., constructed by sorting all outbound trailers in a single planning horizon according to their pre-set departure times. Starting at the first dock door, each succeeding door is assigned to the next outbound trailer.
- *Associate each inbound trailer with a set of outbound trailers.* Each inbound trailer contains load-carriers for multiple outbound trailers. Due to the order release policy at the NDCs, inbound trailer always consist of load-carriers for a set of outbound trailers with consecutive departure times. Each inbound trailer spans a specific range of outbound trucks, depending on the freight volumes per store.

- *Assign dock doors.* Inbound trailers are positioned as close as possible to the middle of the set of its outbound trailers. The outbound trailer initially assigned to that dock door, as well as all the succeeding outbound trailers, are shifted one dock door. When all doors are assigned once, the next outbound trailer is assigned to the first dock door. This procedure is referred to as starting a new cycle.

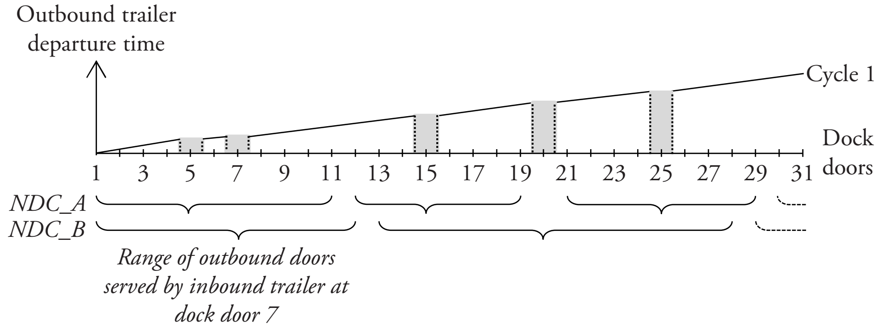

Figure 5.6: The new dock door assignment policy

Relocating preparatory cross-docking activities

The second experimental factor includes a distribution network re-design and a resulting possibility to change the scheduled arrival times of inbound trailer at the cross-dock.

With regard to the distribution network re-design, we consider which cross-docking related operations are performed where in the distribution network. Whereas the basic cross-docking operations (i.e., unloading, moving, and loading) are necessarily performed at the cross-dock, other cross-docking related operations may also be performed elsewhere in the distribution network. Particularly, this chapter addresses two preparatory cross-docking operations: clustering and sorting. *Clustering* is the process of grouping loads that are bound for the same store delivery moment; s*orting* arranges clusters of loads according to the due dates of their corresponding outbound trailers. Sorting and clustering can be performed either at the cross-dock (i.e., upon unloading inbound trailers) or at another logistics facility upstream in the distribution network. By performing preparatory cross-docking activities upstream, the inbound trailer loads can be configured according to the operations at the cross-dock. This approach is comparable to the sequenced-part-delivery as commonly applied in the automotive industry (Ding and Sun, 2004). Figure 5.7 presents a simplified illustration comparing the original situation with the situation in which clustering and sorting are performed upstream in the distribution network.

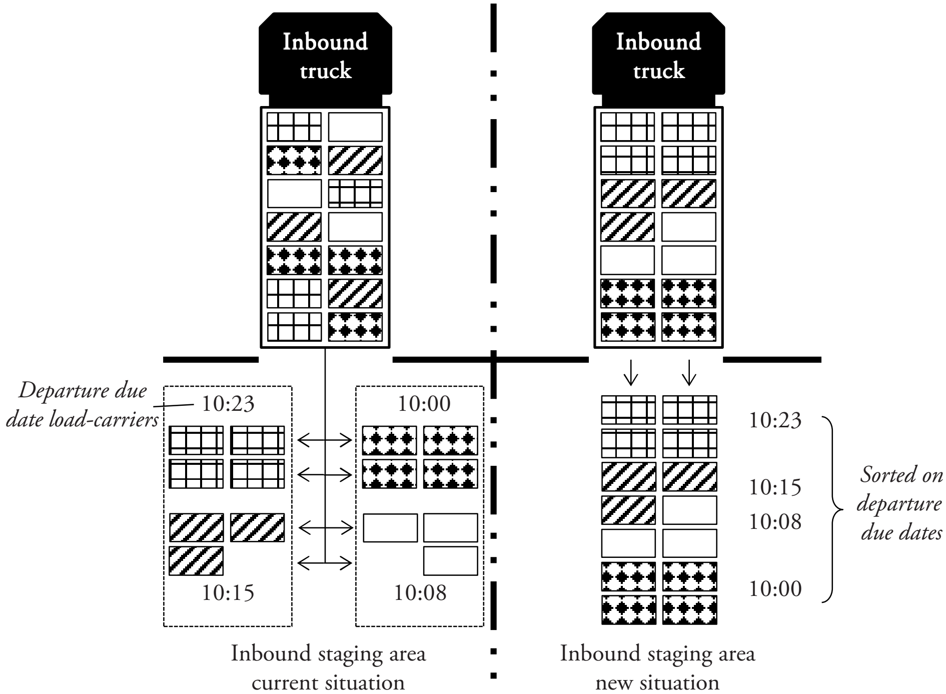

Figure 5.7: Changes inbound staging area due to proposed distribution network re-design

Inbound trailers at the cross-dock always contain load-carriers destined for those outbound trailers with the most proximate departure time. The arrangement of load-carriers inside inbound trailers is random, however. Upon unloading, the load-carriers bound for the same store are currently clustered at the inbound staging area. As a result of the complexity of typical inbound trailer loads and the lack of space available at the cross-dock's inbound staging areas, material handlers are not able to sort clusters of load-carriers. Since the pallet trucks require considerable maneuvering space to collect a batch of load-carriers, the material handlers work through the queue of clustered load-carriers according to a first come first serve policy. Consequently, movements are performed in an arbitrary sequence that could cause load-carriers with the most proximate due-date to be moved lastly. In the case of sorted and clustered inbound trailer loads, clustering has no longer to be performed locally. More importantly, sorted inbound trailer loads enable material handlers to always unload and handle those load-carriers with the most proximate due date first. As will be explained in detail in the results section (Section 5.6), sorted trailer loads considerably reduce the variability of internal cross-dock operations, which renders the opportunity to postpone inbound trailer arrivals and enhance the just-in-time supply of the cross-dock.

5.5.2 Simulation model

Siemens' software package "Tecnomatix Plant Simulation" is used to develop a simulation model and analyze four scenarios. Scenario A1 represents the current cross-docking operations and serves as a baseline for the other scenarios. Scenario A2 introduces the new dock door assignment policy; Scenario A3 the situation where preparatory cross-dock activities are performed upstream in the distribution network and inbound trailer arrival times are postponed. Scenario A4 combines the changes proposed in scenarios A2 and A3. Figure 5.8 shows an overview of the simulation model developed to investigate the scenarios.

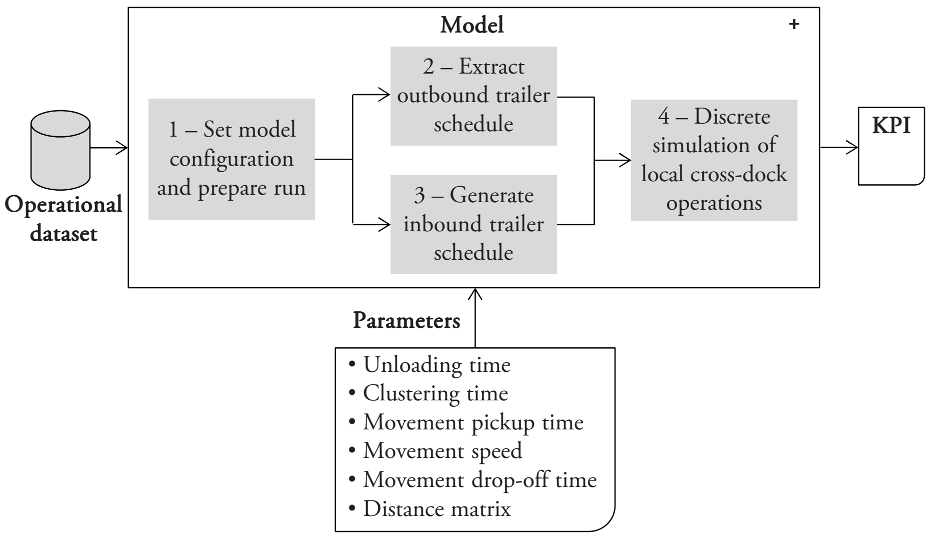

Figure 5.8: An overview of the simulation model

The simulation model consists of four modules. *Module 1* prepares the simulation run by drawing a sample from the store demand volume distribution and configuring the experimental factors according the scenario under study. *Module 2* extracts the outbound trailer departure times from the operational dataset. *Module 3* applies the current logic of the retailer's distribution network planning department to generate the inbound trailer schedule, i.e., setting inbound trailer load compositions and arrival times at the cross-dock. *Module 4* comprises the discrete simulation model for the local cross-dock operations, i.e., implementing the conceptual model described in Table 5.2 and Figure 5.4. The store demand volumes and trailer schedules determined by the first three modules are used as input.

Due to the stochastic nature of the real-world operational setting, as described in the Section 5.4, not every week of cross-dock operations is the same. In order to account for randomness, multiple runs of the simulation model are needed to generate output data which can be statistically analyzed (Evers and Wan, 2012). The beginning of the week (i.e., Monday) is set as starting point of the simulation. At that time, the real-world system is empty. At the end of each day, the cross-dock system is empty again. Due to the large variation in freight flows through the cross-dock from day to day, the natural end point of a single simulation run is at the end of the week (i.e., Sunday). Experiment validity is ensured by applying the confidence interval method at a significance level of 5% (Robinson, 2004). Pilot tests showed that 60 run were required for each scenario, where each run simulates a full week of operations.

5.5.3 Performance measures

The output of the simulation model contains values of eight key performance indicators (KPIs), separated in three types: *general*, *material handling*, and *just-in-time*. The range of KPIs is based on performance measures in prior studies and complemented with typical measures from practice that were obtained from expert interviews with the retailer's managers. Table 5.3 lists the resulting set of cross-dock KPIs. Their mutual relations are shown in Figure 5.9.

At a distribution network level, the retailer's main performance objectives are to maximize the *retail store delivery service level* and *trailer utilization rate*. The service level of retail store deliveries corresponds to the extent to which a store receives all its ordered products within the agreed period of time. The retailer considers it to be the most important performance indicator at the distribution network level. From the perspective of the local cross-dock operations, this network level performance indicator implies that each outbound trailer should depart the cross-dock on-time, while loaded with all load-carriers ordered by the corresponding stores. In accordance with the retailer's current KPIs, we measure store delivery service levels at the local cross-dock level by means of *"load-carrier slack"*. A negative slack value reflects a load-carrier that has missed its outbound trailer. With regard to the trailer utilization rate, the real-world and modelled planning logic imposes fully loaded trailers on NDC-RDC network routes. Trailer utilization rates on the other routes in the distribution network are not within the scope of this study.

Table 5.3: Overview of the local cross-dock KPI adopted in this study

Type	KPI		Description	Measures (unit)
General	G-1	Number of load-carriers on-site	Number of load-carriers on site during operations.	μ and max (load-carriers)
	G-2	Number of unprocessed load-carriers on-site	Number of load-carriers on site that is either waiting to be moved or in currently moved	μ and max (load-carriers)
	G-3	Load-carrier lifespan	Total time that the load-carrier spend on-site (departure time minus arrival time).	μ and σ (seconds)
	G-4	Percentage of un-movable load-carriers	Percentage of the total cross-dock volume that cannot be directly moved to its destination as its outbound dock is still occupied.	μ (percentage of total cross-dock throughput)
Material Handling	MH-1	Load-carrier internal travel distance	Distance travelled by a load-carrier from inbound to outbound door.	μ (meters)
	MH-2	Load-carrier movement-time	Time needed to pickup, move, and drop-off a load-carrier.	μ and σ (seconds)
Just-In-Time	JIT-1	Load-carrier waiting time	Time between the arrival of a load-carrier at inbound staging area and its pickup.	μ and σ (seconds)
	JIT-2	Load-carrier slack	Time between load-carrier drop-off at outbound staging area and its scheduled loading time.	μ and σ (seconds)

Insights are drawn from the simulation outputs by analyzing KPI changes from one scenario to another. Changes in KPIs for each scenario are statistically tested using a one-way ANOVA or Welch ANOVA—depending on the equality of variances—at a 0.05 significance level. Normality of the output data-series is assessed by visual inspection of Normal Q-Q Plots. Boxplot inspections revealed no outliers in the data. Some of the data-series showed skewness or positive kurtosis. Given the fact that the one-way ANOVA is fairly robust to deviations from normality, particularly under equal sample sizes (Lix *et al.*, 1996), the ANOVA tests were applied anyway.

In the case of considerable KPI changes, a Games-Howell or Tukey HSD post-hoc test is performed to identify whether the difference in means between individual scenarios was significant. Finally, effect sizes are calculated using Cohen's d, indicating the standardized difference between the two means. All test values can be found in the *supplementary digital content*[3].

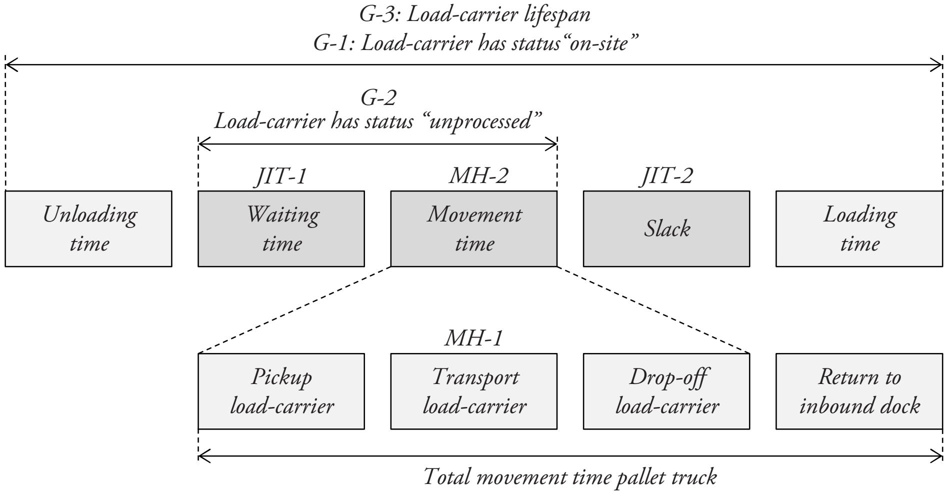

Figure 5.9: The relation between the different KPI considered in this study

5.6 Simulation results

This section starts with a concise overview of the KPI baseline values in Table 5.4. Subsequently, we present the performance effects of the experimental factors. For the sake of brevity, we limit our discussion to those KPIs that show a considerable change from one scenario to another, i.e., >2 % or percentage point (pp).

Table 5.4: Overview of KPI values for Scenario A1

	G-1 LCs on-site		G-2 Unprocessed LCs on-site		G-3 Lifespan		G-4 Unmovable LCs		MH-1 Travel distance		MH-2 Movement time		JIT-1 Waiting time		JIT-2 Slack	
A1	µ	275	µ	41	µ	9568	µ	0.56%	µ	54.9	µ	97	µ	778	µ	5770
	max	703	max	258	σ	1829					σ	15	σ	542	σ	1943

[3] *For the sake of brevity, the detailed test values are not included in the thesis; however, the supplementary digital content is available from the authors upon request.*

5.6.1 New dock door assignment policy

Table 5.5 shows that the new dock-door assignment policy (Scenario A2) reduces the average internal travel distance by 43.5% and movement time by 16.4%. These reductions are not proportional due to the fact that the new policy only affects travel distances; whereas the movement time of a load-carrier through the cross-dock also includes a pickup and drop-off time element.

Table 5.5: Comparison of Scenarios A2 and A1

	G-4 Unmovable LCs		MH-1 Travel distance		MH-2 Movement time		JIT-1 Waiting time	
A2 <-> A1	Δ	+12.0 pp	Δμ	-43.5%	Δμ Δσ	-16.4% +58.3%	Δμ Δσ	-3.1% +14.5%

Figure 5.10 details the travel distance reductions in a histogram. It shows that the new dock door assignment policy results in large travel distance reductions for most movements. Some movements suffer from a considerable increase in travel distance, however. The increased variability in travel distance per movement—and also in load-carrier movement and waiting times—is inherent to the proposed policy. When this policy has reached the last dock door at the cross-dock, a new cycle is started. An inbound trailer that is assigned in a new cycle often contains some load-carriers that are bound for outbound trailers from the previous cycle, i.e., with a dock door at the other end of the cross-dock. Those load carriers have to be moved almost the maximum distance possible.

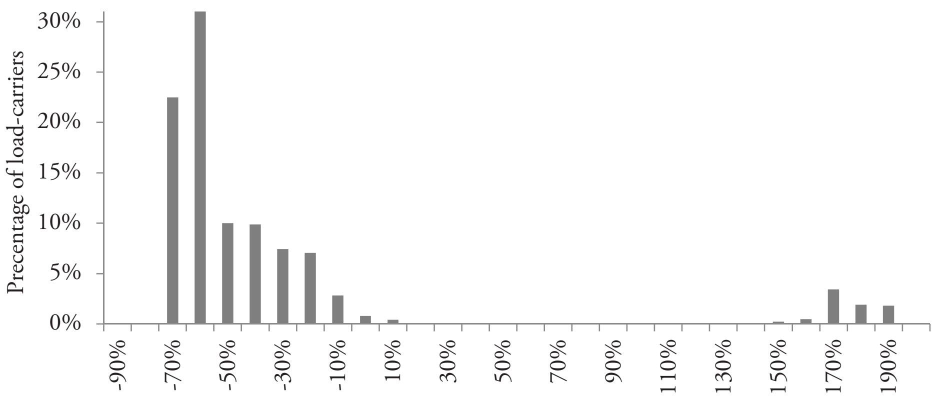

Figure 5.10: Histogram of the travel distance reduction per movement

A negative effect of the new dock door assignment policy is the considerable increase in unmovable load-carriers, i.e., increasing from 0.5% of the throughput to 12.5%. This increase can be explained by the different service modes and cycle times of dock doors in this scenario. In the case of an exclusive service mode (i.e., with dedicated inbound and outbound dock doors) arriving inbound trailers can be served directly at a dock door when the preceding trailer at that door has been unloaded and the inbound staging area has been cleared. On average, this takes 60 minutes. In the case of a mixed service mode, all dock doors are assigned in cycles and a door can only be assigned to an inbound trailer once per cycle. The average cycle time after implementing the new dock door assignment policy is 3:08 hours. Hence, the inbound dock door utilization ratio drops considerably. As a consequence of the reduced inbound dock door utilization ratio the overall utilization of dock door is reduced as well. Comparing the current and new dock door assignment policies, the average buildup time of outbound trailer loads is reduced from 3:21 to 3:08 hours. This reduction in buildup time leads to an increase in the number of load-carriers that cannot be moved to their outbound dock directly after unloading as the previous outbound truck has not departed yet.

Nonetheless, the new dock door assignment results in a travel distance reduction of the pallet trucks in the cross-dock with 137 kilometers each week. A discussion of the simulation results with the cross-dock managers revealed two additional benefits that are not directly observable from the simulation outputs. Firstly, the congestion of material handling equipment inside the RDC (including the equipment dedicated to the warehousing functions) can be reduced due to the fact that cross-docking freight flows are concentrated to one particular area of the cross-dock at a time. Secondly, for similar reasons, the safety for material handlers is improved.

5.6.2 Relocation of preparatory cross-docking activities

Supplying the cross-dock with sorted and clustered inbound loads has two effects on local cross-dock operations. Firstly, the time to unload an inbound trailer is reduced as clustering has no longer performed to be at the cross-dock. This leads to an average local time-saving of 8 minutes per inbound truck. Secondly, the arrival of sorted inbound loads enables the material handlers to always move the load-carriers with the most proximate outbound departure time first. This results in more stable and predictable material handling operations inside the cross-dock. Accordingly, the standard deviation of the load-carriers' slack at the outbound staging area reduces. Recall that this local performance indicator reflects the service level of retail store deliveries. Figure 5.11 plots the slack of the individual load-carriers for the current situation (A1) and the situation with sorted and clustered inbound loads (A1 + clustered and sorted trailers). In both situations, the load-carrier slack fits a normal distribution (Anderson-Darlings test of normality, at $p < 0.01$). The reduced standard deviation renders the opportunity to postpone inbound trailer arrival with almost 14 minutes, without increasing the probability of a load-carrier missing its connection in comparison with the current situation, i.e., practically zero probability.

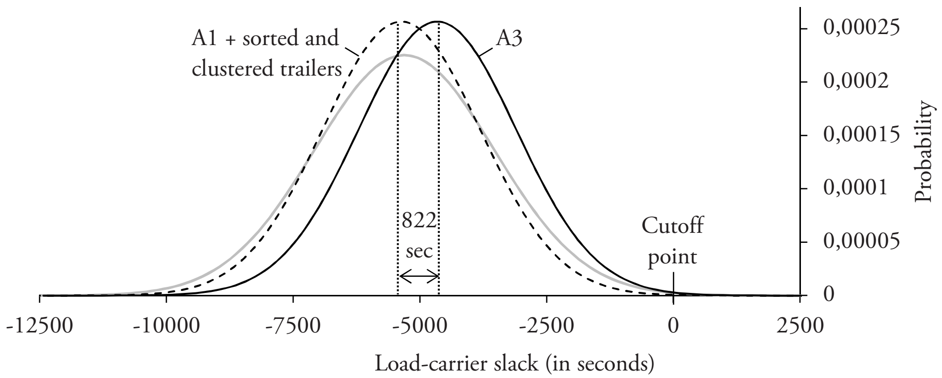

Figure 5.11: Distribution of load-carrier slack (JIT-2)

Due to the combined positive effects of relocating the preparatory cross-docking activities to a facility upstream in the distribution network, inbound trailer arrivals are postponed with 22 minutes in Scenario A3. As a result, load-carriers arrive more timely at the cross-dock, which in turn affects multiple KPIs as shown in Table 5.6.

Table 5.6: Comparison of Scenarios A3 and A1

	G-1 LCs on-site		G-2 Unprocessed LCs on-site		G-3 Lifespan		JIT-1 Waiting time		JIT-2 Slack	
A3 <-> A1	Δμ Δmax	-12.9% - 9.0%	Δμ Δmax	-19.8% - 8.3%	Δμ Δσ	-14.6% -0.3%*	Δμ Δσ	-6.7% -0.5%*	Δμ Δσ	-15.4% -13.0%

** The mean difference is not significant at the 0.05 level.*

Table 5.6 shows that the average lifespan of load-carriers drops by 14.6% and the average slack by 15.4%. As a result, there are 12.9% less load-carriers on-site on average. The shorter unloading processes results in a reduction of the average number of unprocessed load-carriers (work in progress; WIP) by 19.8%. These KPI improvements translate into an enhanced facility utilization, which postpones the need for large capacity expansion investments when freight volumes increase. Although a thorough analysis of the required re-design of NDC operations lies beyond the scope of this study, discussions with the retailer's distribution network managers suggests that additional time needed at the NDC to perform the sorting and clustering activities is at most equal to the 8 minutes saved at the cross-dock. Indeed, the managers anticipate that performing the preparatory cross-docking activities closer to the place where the load-carriers are order-picked is more efficient.

5.6.3 Applying both changes

Table 5.7 shows the KPI values when both changes are applied (i.e., Scenario A4).

Table 5.7: Comparisons of Scenarios A1 through A4

	G-1 LCs on-site	G-2 Unprocessed LCs on-site	G-3 Lifespan	G-4 Unmovable LCs	MH-1 Travel distance	MH-2 Movement time	JIT-1 Waiting time	JIT-2 Slack
A2 <-> A1				Δ +12pp	$\Delta\mu$ -43.5%	$\Delta\mu$ -16.4% $\Delta\sigma$ +58.3%	$\Delta\mu$ -3.1% $\Delta\sigma$ +14.5%	
A3 <-> A1	$\Delta\mu$ -12.9% Δmax -9.0%	$\Delta\mu$ -19.8% Δmax - 8.3%	$\Delta\mu$ -14.6% $\Delta\sigma$ -0.3%*	Δ - 0.5pp			$\Delta\mu$ -6.7% $\Delta\sigma$ -0.5%*	$\Delta\mu$ -15.4% $\Delta\sigma$ -13.0%
A4 <-> A1	$\Delta\mu$ -13.1% Δmax -9.2%	$\Delta\mu$ -29.8% Δmax-12.3%	$\Delta\mu$ -14.6% $\Delta\sigma$ -0.1%*	Δ +6.5pp	$\Delta\mu$ -43.3%	$\Delta\mu$ -15.9% $\Delta\sigma$ +58.8%	$\Delta\mu$ -20.5% $\Delta\sigma$ -10.1%	$\Delta\mu$ -13.1% $\Delta\sigma$ -12.3%

** The mean difference is not significant at the 0.05 level.*

Overall, Table 5.7 indicates that the new dock door assignment policy impacts another set of KPI than the relocation of preparatory cross-docking activities plus the postponed arrival of inbound trailers. Indeed, changes in four KPIs in Scenario A4 can almost be completely attributed to either Scenario A2 or A3 (i.e., G-1, G-3, MH-1, and MH-2). This can be explained by the differences in the targeted performance domains. Scenario A2 aims to increase material handling efficiency, whereas Scenario A3 mainly aims to improve the just-in-time arrival of load-carriers at the cross-dock flows. The remaining KPIs are affected by both changes. Firstly, the simulation results indicate that the new dock door assignment results in a shorter build-up time at the outbound staging areas, which results an increased number of unmovable load-carriers. However, the reduced built-up time is partly balanced by an enhanced just-in-time arrival of inbound loads in Scenario A3. Secondly, applying the new dock door assignment policy alone yields a 3.1% average waiting time reduction. A just-in-time supply of inbound trailers reduces the average waiting time by 6.7%. Combining the improved material handling efficiency (Scenario A2) and effectiveness (Scenario A3), Scenario A4 shows a 20.5% reduction in waiting time. As a consequence also the number of unprocessed load-carriers (WIP) reduced significantly.

Lastly, we analyze the simulation results to put the individual KPI into a broader cross-docking performance context. Figure 5.12 shows how the lifespan of a load-carrier can be decomposed in individual material handling and just-in-time KPIs, using average values from Scenario A4. Combined, Table 5.7 and Figure 5.12 suggest that the effects of the new dock door assignment on overall cross-docking performance are limited. According to the just-in-time nature of the cross-docking strategy, many KPIs in practice are time-related. The reduced internal travel distance as a result of the new dock door assignment, albeit considerable, has little impact on time-related KPIs. Not surprisingly, the time-related KPIs are strongly improved by a more just-in-time arrival of load-carriers at the cross-dock.

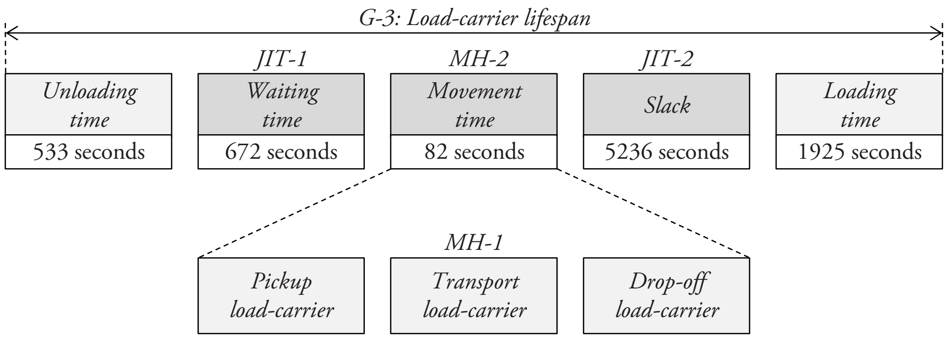

Figure 5.12: Relations between the time-related KPI values

5.7 Discussion

Below, we discuss the practical and theoretical implications that can be derived from our study.

5.7.1 Practical implications

The design and control of distribution network logistics often impose constraints on the planning of operations at the cross-dock. This study proposed a new, dynamic dock door assignment policy, which takes those network level constrains into account. Although the degree of material handling efficiency improvement may strongly differ from one cross-dock to another, our case show that a >40% reduction of internal travel distance is feasible when applying the proposed dock door assignment policy. Accordingly, the dock door assignment policy resulted in considerable cost savings, reduced congestion, and improved material handler safety.

Furthermore, this chapter illustrates the important role of distribution network decision-making in local cross-dock operations. Local cross-dock performance can be considerably improved by performing preparatory sorting and clustering activities at a logistics facility upstream in the distribution network. The corresponding re-design of the distribution network enables an enhanced just-in-time arrival of inbound trailer loads, which leads to strong reductions in the average and maximum number of load-carriers at the cross-dock and the time load-carriers spend on-site. These performance improvements strongly relate to the capacity of a cross-dock in terms of its throughput, staging capacity, and size of the facility. An enhanced just-in-time arrival of inbound loads can thus postpone the need to make considerable investments to expand cross-dock capacity.

5.7.2 Theoretical implications

The results of our study provide illustrative empirical evidence for the need to consider the interdependencies between local and network-wide cross-docking operations. Specifically, three important theoretical contributions can be derived from our results. Firstly, a new policy is presented that dynamically assigns dock doors to inbound and outbound trailers. A thorough validation of the retail distribution network setting under study revealed the inbound and outbound trailer load compositions and arrival/departure times as key constraints imposed by network level planning. By addressing these network level constraints, the new dock door assignment policy results in a considerable reduction in internal travel distance.

Secondly, considering a range of cross-docking performance indicators typically used in practice, the simulation results reveal that the internal travel distance reduction associated with the new dock door assignment does not translate proportionally into overall cross-docking performance. This is due to the fact that the movement time through the cross-dock constitutes only a fraction of a load-carrier's total lifespan at the cross-dock. Accordingly, the generally adopted assumption that internal travel distance is a good proxy for overall cross-docking performance is debatable. Rather, it should be considered as one of many performance indicators.

Thirdly, the chapter illustrates that opportunities in the design and control of the distribution network can be exploited to realize easily obtainable cross-docking performance improvements. Performing preparatory cross-docking activities upstream in the distribution network serves as an example in that regard. Our simulation results show how this distribution network re-design results in more stable and predictable material handling operations at the cross-dock. The corresponding improvements in local cross-dock operations render the opportunity to postpone the arrival of inbound trailer loads, which substantially improves overall cross-docking performance.

5.8 Conclusions

This chapter argues that researchers and practitioners should carefully consider the interdependencies between local cross-dock and network-wide logistics operations when designing and implementing policies to improve their cross-docking processes. Out of the many papers proposing cross-docking improvement policies, few have considered network and local cross-docking problem aspects simultaneously. While prior work has pointed to this gap in research, the value of considering both local cross-dock and network-wide logistics operations was never quantified nor illustrated in detail.

Albeit exploratory, this chapter provides empirical evidence quantifying the impact of a typical distribution network re-design and a change in transportation planning on a range of cross-docking performance measures. The performance improvements were compared against the impact of a typical local cross-dock planning policy. To that end, a new dock door assignment policy was proposed and evaluated. We analyzed changes in a range of performance indicators used in cross-docking practice. Our analyses indicate that deliberate decision-making at a distribution network level may have a larger impact on cross-docking performance than when local operations are considered in isolation.

Chapter 6.

Discussion and conclusions

6.1 Introduction

The far-reaching globalization and specialization of supply chains and the advent of the just-in-time philosophy have fragmented the flows of goods between partners in the supply chain. When operating in isolation, logistics service providers often struggle to sustainably meet the logistics requirements that stem from these trends. Therefore, distribution logistics is faced with an increased and inefficient use of heavily polluting logistics resources, such as trucks and warehouses. The main purpose of this thesis is to contribute to the sustainability of distribution logistics by studying collaboration among partners and competitors in distribution networks. Specifically, the thesis conceptualizes horizontal and vertical collaboration in distribution networks with cross-docks and studies innovative logistics solutions in that regard. Generally, the solutions proposed in this thesis have shown to substantially improve the utilization of logistics resources (i.e., trucks and cross-dock facilities) and the economic viability of the logistics service providers participating in this research. Below, the main research findings from each chapter are summarized. The thesis is concluded with a vision for future research on horizontal and vertical collaboration.

6.2 Main findings

Chapters 2 and 3 describe studies exploring the area of horizontal collaboration between autonomous freight carriers. Chapter 2 lists the main challenges with joint operational decision-making among autonomous freight carriers and precisely explains the role of IT therein. Case studies at multiple planning departments of European freight carriers show that collaborating carriers face fundamental challenges with the planning and control of their joint transport operations—despite the broad availability of state-of-the-art IT. A technology-oriented typology is proposed that explains how inherent technological differences between IT application types result in integration issues that hinder joint operational planning and control. Within the boundaries of a single decision-making unit, those integration issues primarily appear in updating transaction processing system applications with constantly changing information from decision support or real-time systems. As a result, transaction processing systems do not fully reflect the real-time situation, nor do they show the intended decisions and scenarios considered by transportation planners. Chapter 2 shows that IT connections across the boundaries decision-making units only exist between transaction processing systems. Due to the local IT integration issues, planners are not provided with the real-time situation or preliminary decisions made at collaborating carriers. The lack thereof explains why joint operational planning and control is hardly encountered in practice.

Chapter 3 addresses the practice of Operations Research in horizontal carrier collaboration. To this end, it presents an overview of literature addressing aspects of the vehicle routing problem underlying the joint route planning problem of collaborating carriers. A comparison between the academic state-of-the-art and current practice indicates that literature only addresses aspects of the more generalized routing problem faced by collaborating carriers. Furthermore, Chapter 3 proposes and evaluates heuristics to re-structure and intensify the joint route planning procedures between two autonomous business units at a Dutch logistics service provider. The experimental results show that the collaborative procedures currently in place improved the efficiency of distribution routes in terms of the kilometers traveled (-19%). The best performing heuristic proposed in Chapter 3 further improves distribution efficiency with 7%, which corresponds to an approximate yearly cost saving of 260 K€. Lastly, Chapter 3 formulates recommendations regarding the managerial and organizational changes required to enable using the heuristic in their daily planning procedures.

Chapters 4 and 5 describe studies exploring the area of vertical collaboration in distribution networks with cross-docks. In these chapters, it is argued that the absence of storage buffers in such networks results in particularly strong interdependencies between local cross-dock operations and distribution network logistics. This emphasizes the need to adopt a network orientation when cross-docking is part of a firm's logistics strategy. Chapter 4 proposes a framework specifying the interdependencies between different cross-docking problem aspects. The framework aims to support future research in developing decision models for synchronizing local cross-dock operations and distribution network logistics. Chapter 4 also presents a new general classification scheme for cross-docking research. Despite the just-in-time nature of the cross-docking strategy, the classification of research reveals that few papers have taken a network orientation when proposing cross-docking improvement policies. Rather, most existing policies consider local cross-dock operations in isolation. In order to highlight the importance of synchronization in cross-docking networks, Chapter 4 describes two real-life illustrative problems that are not yet addressed in the literature.

Whereas the arguments for the need to synchronize local cross-dock and distribution network logistics in Chapter 4 mainly rely upon logical reasoning and observations, Chapter 5 provides quantitative empirical illustrative evidence in that regard. Specifically, it identifies and explains the constraints imposed on local cross-dock operations by distribution network planning in the setting of an international grocery retailer. Furthermore, a new local cross-dock planning policy (which carefully considers the network level constraints) and a distribution network re-design (which carefully considers local cross-dock operations) are proposed to improve cross-docking performance. The chapter describes a simulation model that is developed to compare and evaluate the performance effects of the proposed changes against the current operations at the retailer. In line with their targeted performance domains, the proposed local planning policy primarily improves material handling efficiency (i.e., the internal travel distance of goods through the cross-dock is reduced with

42%); whereas the distribution network re-design improves the average lifespan of goods on-site (-15%), work-in-progress (-20%) and amount of goods inside the cross-dock (-13%). The latter performance indicators translate into an improved utilization of the cross-dock facility and a reduction in distribution lead-times. In line with the just-in-time nature of the cross-docking strategy, the results indicate that adopting a network orientation in developing cross-docking improvement policies has a larger impact on cross-docking performance than when only local operations are considered.

6.3 Research contributions

A primary contribution of this thesis resides in the adopted multi-disciplinary research approach. It considers concepts from Operation Research, Information Systems and Supply Chain Management theory and practice. Accordingly, Table 6.1 highlights the main research contributions with regard to these academic disciplines.

Table 6.1: The main research contributions of this thesis

		Horizontal collaboration		Vertical collaboration
OR	Ch. 3	- Defines the generalized pickup and delivery problem – being the routing problem underlying typical horizontal carrier collaborations. - Discusses how aspects of the generalized pickup and delivery problem are addressed in OR literature. - Proposes a heuristic supporting the joint route planning between autonomous freight carriers in practice.	Ch. 4	- Presents a research classification of local and network-wide cross-docking models. - Identifies avenues for future research. - Presents illustrative cross-docking synchronization problem descriptions for future OR modelling.
			Ch. 5	- Proposes and evaluates a local cross-dock planning policy and network re-design to improve the overall cross-docking performance within a large retail-distribution network in practice.
IS	Ch. 2	- Proposes a technology-oriented typology for IT applications - Uses the proposed typology to identify IT integration issues that hinder joint operational decision-making.	Ch. 4	- Develops a framework specifying input/output characteristics among individual cross-docking decision problems that can be used to develop new IT applications supporting cross-docking management.
SCM	Ch. 2	- Conceptualizes joint planning and control among collaborating, yet autonomous, freight carriers. - Identifies the challenges freight carriers face in that regard.	Ch. 5	- Provides empirical quantitative evidence illustrating the need for a supply chain orientation in managing cross-docking operations.
	Ch. 3	- Formulates recommendations for managerial/organizational changes required to implement the proposed heuristic for the support of joint route planning. - Provides illustrative empirical evidence quantifying the benefit of horizontal collaboration among autonomous freight LTL carriers.		

6.4 Directions for future research

Due to its explorative nature, the research presented in this thesis exposes many opportunities for future research.

6.4.1 Horizontal collaboration

The research on horizontal collaboration between autonomous carriers presented in this thesis gives rise to promising areas for future studies in Operations Research, Information Systems and Supply Chain Management research.

As discussed in Chapter 3, problem formulations and solution methods covering the full extent of the routing problem faced by horizontally collaborating carriers have not yet been proposed in the literature. Two opportunities for future Operations Research emerge from this gap in the literature. Firstly, Chapter 2 shows that collaborative transport operations often include redirecting a load to one or more cross-docks. Accordingly, the transshipment of loads at a cross-dock is essential to the joint planning problem of collaborating carriers. Transshipments in this context fundamentally differ from transshipments considered in existing routing problem formulations and solution methods. That is, in a realistic collaborative carrier context, the time windows and lead-time requirements of most transportation requests allow its load to be redirected to a cross-dock. This drastically increases the number of possible routes. Future studies could be aimed at modelling transshipments of loads in the joint route planning problems of collaborating carriers and validate those models with data from cases.

Besides the above described line, which is grounded in fundamental Operations Research literature, a promising area for future research resides in more application-oriented studies. In order to develop methods that can be deployed for the purpose of supporting planners in a collaborative carrier setting, future research should propose means to reduce the size and scope of the underlying routing problem, e.g., by considering parts of the problem in isolation or proposing sequential or iterative heuristics to solve multiple problem aspects. The work in Chapter 3 can serve as an example therein. There, the scope of the underlying routing problem was reduced by considering only delivery loads. Moreover, a heuristic is proposed that iteratively determines the allocation of delivery requests to each depot and then solves the remaining routing problems for the depots separately. Future studies could be aimed at expanding the scope of the heuristic proposed in Chapter 3 or develop more sophisticated mathematical methods to improve its performance. Furthermore, the proposed approach can be deployed at the planning departments of other collaborative freight carriers to derive stronger empirical proof for its benefits.

As the research focus shifts towards the deployment of joint planning methods in real-world collaborative carrier settings, it follows from the research presented in this thesis that information systems and supply chain management issues emerge. The role of IT in horizontal carrier collaboration is explained in detail in Chapter 2. It shows that the current IT development efforts are aimed at facilitating inter-organizational information exchange by means of connections between transaction processing systems of collaborating carriers. Information from other types of widely used information systems (e.g., decision support and real-time systems) are not easily exchanged through these inter-organizational connections, due to the IT integration issues described in Chapter 2. As a result, there is a strong need for IT solutions that facilitate direct connections between the decision support systems of collaborating carriers. The same holds for direct connections between and real-time systems, such as fleet telematics systems. Given the technological characteristics of these types of systems, the development and use of such solutions is far from trivial—and hence a promising area for future research.

From a supply chain management perspective, literature emphasizes the importance of appropriately selecting partner carriers and setting up governance structures (Cruijssen *et al.*, 2007a; Schmoltzi and Wallenburg, 2012). While valuable in itself, the outcomes from such strategy-oriented research are of limited use to carriers that aim to effectively utilize a readily established partner network. At an operational level, the decision-making processes of the human planners at collaborating carriers are crucial for realizing the acclaimed benefits of horizontal collaboration. Nevertheless, it is still unclear what drives or impedes planners in, for example, forwarding transportation requests to a partner carrier—or, alternatively, what makes that requests are not considered for forwarding. This lack of understanding raises interesting research questions regarding organizational and behavioral aspects of horizontal carrier collaboration. Promising areas for future research in that regard are concerned with understanding how the daily tasks of planners change as a result of the horizontal collaboration (e.g., Cegarra and Van Wezel, 2011) and how existing performance indicators can be altered to measure the extent to which planners exploit the synergies that emerge from the horizontal collaboration. Although these topics were not the focus of this thesis, the work in Chapters 2 and 3 clearly indicates the importance of these operational level aspects and the role of the human planners therein.

6.4.2 Vertical collaboration

The vision for future research on vertical collaboration in distribution logistics is based on a comparison between the academic and industry perspectives on cross-docking. The research projects conducted for this thesis are performed in close cooperation with many companies that are active in distribution logistics and operate one or multiple cross-docks. Generally, the projects indicate a partial mismatch between the recent focus of Operations Research literature and the cross-dock settings and problems encountered in practice. A more elaborate description of the comparative analysis is presented in Buijs and Vis (2014). Two key differences between the academic and industry perspectives on cross-docking indicate several new challenging research problems—as outlined below.

Firstly, the main difference is found in how the cross-dock's distribution network is considered. In practice, most cross-docks are managed as cost centers, with the sole purpose to enable the consolidation of freight in its distribution network, preferably at the lowest possible additional transportation, facility and holding costs. The majority of academic cross-dock optimization studies assume that the tightly related network decisions (e.g., trailer arrival and departure times) can be imposed according to cross-dock operational preferences. In industry, the decision latitude in that regard is often rather limited. Indeed, from a cross-dock perspective, most network decisions are a fait accompli. Many cross-docks are, for example, simply confronted with given inbound arrival times and outbound departure deadlines. Accordingly, future research should adopt a network orientation with the aim to enable synchronization of local cross-dock operations and network-wide logistics by carefully considering the interdependencies between individual decision problems. A detailed list of the opportunities for future research that stem from this mismatch is presented in Chapter 4.

Secondly, logistics managers consider another, wider range of cross-docking performance indicators than typical academic studies. A focus on minimizing the makespan—which is the most considered objective function in literature—is seldom encountered in practice. Rather, the makespan is often considered fixed and the focus is on minimizing the workforce required to handle the total freight volume within that makespan. A frequently used measure for workforce efficiency in academic studies is the inner travel distance of material handling equipment. Although useful when determining the layout of a cross-dock, the inner travel distance alone does not fully reflect workforce efficiency at an operational level. Accordingly, in industry, cross-dock managers often use performance indicators reflecting the lead time of goods on-site and the maximum floor capacity needed during the shift. The research presented in Chapter 5 placed the often-used academic performance indicators in a more holistic cross-docking performance context and showed how different cross-docking improvement policies affect different performance indicators. Future cross-docking research is encouraged to adopt a wide range of performance indicators to ensure that any local or network-wide improvement does not come at the expense of another.

Besides decision support by means of Operations Research methods, efficient cross-docking requires sophisticated information systems to capture accurate and timely information and exchange that information among the relevant stakeholders in the distribution network. Except for earlier, descriptive literature on cross-docking (e.g., Apte and Viswanathan, 2000; Napolitano, 2000), no papers appeared with an explicit focus on information systems requirements or design. A particularly promising area for future research in that regard would address the integration of local cross-dock systems (often included in warehouse management systems) and information systems at a network level (e.g., transportation management systems). Similar to the discussion about horizontal collaboration, realizing such integration may be challenging due to the fact that these systems are operated at multiple autonomous business units or companies.

Lastly, future research could address supply chain management aspects related to cross-docking. The ability to improve cross-docking operations (e.g., by means of a more just-in-time arrival of inbound trailers) depends on the power structure among the partners involved in distribution logistics. As discussed above, published papers assume the cross-dock manager to have control over distribution network logistics, such as trailer arrival times. This thesis reveals that the level of control exerted by cross-dock operators varies strongly—and is generally rather limited. Cross-dock operations in the setting of an LTL freight carrier, for example, are faced with logistics requirements from many stakeholders. The load compositions and the trailer arrival/departure times are determined by an autonomous transport planning department (i.e., an external stakeholder). This planning department, in turn, is strongly constrained by the time-windows specified by their customer (i.e., many external stakeholders). In the face of those requirements, the extent to which cross-dock operational preferences can be translated into network logistics decision-making is limited. In a retail distribution setting, by contrast, it is more likely that cross-dock operational preferences can be considered as part of the overall distribution logistics problem. The reason is that a retailer often either owns, or at least exerts full control over, both cross-dock and network-wide logistics resources. Academic studies to the role of power, and other supply chain management aspects, in distribution networks with cross-docks would greatly contribute our understanding of successful cross-docking.

References

Acar, K., Yalcin, A. & Yankov, D. 2012. "Robust door assignment in less-than-truckload terminals." *Computers and Industrial Engineering 63(4)*: 729–738.

Agustina, D., Lee, C. & Piplani, R. 2010. "A review: Mathematical models for cross docking planning." *International Journal of Engineering Business Management 2(2)*: 47–54.

Albers, S. & Klaas-Wissing, T. 2012. "Organisation of multilateral LTL alliances.", *International Journal of Logistics: Research and Applications 15(3)*: 181–198.

Alpan, G., Ladier, A-L., Larbi, R. & Penz, B. 2011a. "Heuristic solutions for transshipment problems in a multiple door cross docking warehouse." *Computers & Industrial Engineering 61(2)*: 402–408.

Alpan, G., Larbi, R. & Penz, B. 2011b. "A bounded dynamic programming approach to schedule operations in a cross docking platform." *Computers & Industrial Engineering 60(3)*: 385–396.

Alptekinoğlu, A. & Tang, C. S. 2005. "A model for analyzing multi-channel distribution systems." *European Journal of Operational Research 163(3)*: 802–824.

Alumur, S. & Kara, B. Y. 2008. "Network hub location problems: The state of the art." *European Journal of Operational Research 190(1)*: 1–21.

Álvarez-Pérez, G. A., González-Velarde, J. & Fowler, J. 2008. "Crossdocking – just in time scheduling: An alternative solution approach." *The Journal of the Operational Research Society 60(4)*: 554–564.

Apte, U. M. & Viswanathan, S. 2000. "Effective cross docking for improving distribution efficiencies." *International Journal of Logistics Research and Applications 3(3)*: 291–302.

Arabani, A. B., Ghomi, S. F. & Zandieh, M. 2010. "A multi-criteria cross-docking scheduling with just-in-time approach." *The International Journal of Advanced Manufacturing Technology 49(5-8)*: 741–756.

Arabani, A. B., Ghomi, S. F. & Zandieh, M. 2011a. "Meta-heuristics implementation for scheduling of trucks in a cross-docking system with temporary storage." *Expert Systems with Applications 38(3)*: 1964–1979.

Arabani, A. B., Zandieh, M. & Ghomi, S. F. 2011b. “Multi-objective genetic-based algorithms for a cross-docking scheduling problem.” *Applied Soft Computing 11(8)*: 4954–4970.

Arabani, A. B., Zandieh, M. & Ghomi, S. F. 2012. “A cross-docking scheduling problem with sub-population multi-objective algorithms.” *The International Journal of Advanced Manufacturing Technology 58(5-8)*: 741–761.

Auramo, J., Kauremaa, J. & Tanskanen, K. 2005. “Benefits of IT in supply chain management: An explorative study of progressive companies.” *International Journal of Physical Distribution & Logistics Management 35(2)*: 82–100.

Bachlaus, M., Pandey, M., Mahajan, C., Shankar, R. & Tiwari, M. 2008. “Designing an integrated multi-echelon agile supply chain network: a hybrid taguchi-particle swarm optimization approach.” *Journal of Intelligent Manufacturing 19(6)*: 747–761.

Barratt, M. 2004. “Understanding the meaning of collaboration in the supply chain.” *Supply Chain Management: An International Journal 9(1)*: 30–42.

Bartholdi, J. J. & Gue, K. R. 2000. “Reducing labor costs in an LTL crossdocking terminal.” *Operations Research 48(6)*: 823–832.

Bartholdi, J. J. & Gue, K. R. 2004. “The best shape for a crossdock.” *Transportation Science 38(2)*: 235–244.

Berbeglia, G., Cordeau, J-F., Gribkovskaia, I. & Laporte, G. 2007. “Static pickup and delivery problems: a classification scheme and survey.” *TOP 15(1)*: 1–31.

Berger, S. & Bierwirth, C. 2010. “Solutions to the request reassignment problem in collaborative carrier networks.” *Transportation Research Part E: Logistics and Transportation Review 46(5)*: 627–638.

Bhaskaran, S. 1992. “Identification of transshipment center locations.” *European Journal of Operational Research 63(2)*: 141–150.

Bourlakis, M. A. & Bourlakis, C. A. 1999. “Deliberate and emergent logistics strategies in food retailing: A case study of the Greek multiple food retail sector.” *Supply Chain Management: An International Journal 6(4)*: 189–200.

Boysen, N. 2010. “Truck scheduling at zero-inventory cross docking terminals.” *Computers & Operations Research 37(1)*: 32–41.

Boysen, N., Briskorn, D. & Tschöke, M. 2013. “Truck scheduling in cross-docking terminals with fixed outbound departures.” *OR Spectrum 35(2)*: 479–504.

Boysen, N. & Fliedner, M. 2010. "Cross dock scheduling: Classification, literature review and research agenda." *Omega 38(6)*: 413–422.

Boysen, N., Fliedner, M. & Scholl, A. 2010. "Scheduling inbound and outbound trucks at cross docking terminals." *OR Spectrum 32(1)*: 135–161.

Bozer, Y. A. & Carlo, H. J. 2008. "Optimizing inbound and outbound door assignments in less-than-truckload crossdocks." *IIE Transactions 40(11)*: 1007–1018.

Briskorn, D., Choi, B-C., Lee, K., Leung, J. & Pinedo, M. 2010. "Complexity of single machine scheduling subject to nonnegative inventory constraints." *European Journal of Operational Research 207(2)*: 605–619.

Buijs, P. & Vis, I. F. A. 2014. "Comparing industry and academic perspectives on cross-docking operations." In *Progress of Material Handling Research 2014* (in press).

Carbone, V. & Stone, M. 2005. "Growth and relational strategies by the European logistics service providers: Rationale and outcomes." *Transportation Research Part E: Logistics and Transportation Review 41(6)*: 495–510.

Carlo, H. J. & Bozer, Y. A. 2011. "Analysis of optimum shape and door assignment problems in rectangular unit-load crossdocks." *International Journal of Logistics: Research and Applications 14(3)*: 149–163.

Carter, C. R. & Rogers, D. S. 2008. "A framework of sustainable supply chain management: moving toward new theory." *International Journal of Physical Distribution & Logistics Management 38(5)*: 360–387.

Cegarra, J. & Van Wezel, W. 2011. "A comparison of task analysis methods for planning and scheduling." In *Behavioral Operations in Planning and Scheduling* (pp. 323–338), Springer Berlin Heidelberg.

Chen, F. & Lee, C-Y. 2009. "Minimizing the makespan in a two-machine cross-docking flow shop problem." *European Journal of Operational Research 193(1)*: 59–72.

Chen, F. & Song, K. 2009. "Minimizing makespan in two-stage hybrid cross docking scheduling problem." *Computers & Operations Research 36(6)*: 2066–2073.

Chen, P., Guo, Y., Lim, A. & Rodrigues, B. 2006. "Multiple crossdocks with inventory and time windows." *Computers & Operations Research 33(1)*: 43–63.

Chmielewski, A., Naujoks, B., Janas, M. & Clausen, U. 2009. "Optimizing the door assignment in LTL-terminals." *Transportation Science 43(2)*: 198–210.

Choy, K., Chow, H., Poon, T. & Ho, G. 2012. "Cross-dock job assignment problem in space-constrained industrial logistics distribution hubs with a single docking zone." *International Journal of Production Research 50(9)*: 2439–2450.

Closs, D. & Savitskie, K. 2003. "Internal and external logistics information technology integration." *International Journal of Logistics Management 14(1)*: 63–76.

Cohen, Y. & Keren, B. 2009. "Trailer to door assignment in a synchronous cross-dock operation." *International Journal of Logistics Systems and Management* 5(5): 574–590.

Cortés, C., Matamala, M. & Contardo, C. 2010. "The pickup and delivery problem with transfers: Formulation and a branch-and-cut solution method." *European Journal of Operational Research 200(3)*: 711–724.

Crainic, T. G. 2000. "Service network design in freight transportation." *European Journal of Operational Research 122(2)*: 272–288.

Cruijssen F. 2012. Horizontal collaboration: A CO3 position paper. http://www.co3-project.eu/wo3/wp-content/uploads/2011/12/CO%C2%B3-Framework-for-collaboration-Executive-Summary.pdf Last consulted April 10th 2014.

Cruijssen, F., Cools, M. & Dullaert, W. 2007a. "Horizontal cooperation in logistics: Opportunities and impediments." *Transportation Research Part E: Logistics and Transportation Review 43(2)*: 129–142.

Cruijssen, F., Dullaert, W. & Fleuren, H. 2007b. "Horizontal cooperation in transport and logistics: A literature review." *Transportation Journal 46(3)*: 22–39.

De Koster, R., Le-Duc, T. & Roodbergen, K .J. 2007. "Design and control of warehouse order picking: A literature review." *European Journal of Operational Research 182(2)*: 481–501.

Dinalog. 2014. *4C: Cross chain control center.* http://www.dinalog.nl/nl/themes/4c__cross_chain_control_center Last consulted April 10th 2014.

Ding, F.-Y. & Sun, H. 2004. "Sequence alteration and restoration related to sequenced parts delivery on an automobile mixed-model assembly line with multiple departments." *International Journal of Production Research 42(8)*: 1525–1543.

Eisenhardt, K. M. & Graebner, M. E. 2007. "Theory building from cases: Opportunities and challenges.", *Academy of Management Journal 50(1)*: 25–32.

Eksioglu, B., Vural, A. V. & Reisman, A. 2009. "The vehicle routing problem: A taxonomic review." *Computers & Industrial Engineering 57(4)*: 1472–1483.

Elkington, J. 1998. *Cannibals with Forks: The triple bottom line of 21st Century Business*, Capstone Publishers: Oxfort, UK.

Erera, A., Hewitt, M., Savelsbergh, M. & Zhang, Y. 2013. "Creating schedules and computing operating costs for LTL load plans." *Computers & Operations Research 40(3)*: 691–702.

Esper, T. & Williams, L. 2003. "The value of collaborative transportation management (CTM): Its relationship to CPFR and information technology." *Transportation Journal 42(4)*: 55–65.

Evangelista, P., Mogre, R., Perego, A., Raspagliesi, A. & Sweeney, E. 2012. "A survey based analysis of IT adoption and 3PLs' performance." *Supply Chain Management: An International Journal 17(2)*: 172–186.

Evers, P.T. & Wan, X. 2012. "Systems analysis using simulation." *Journal of Business Logistics 33(2)*: 80–89.

Fabbe-Costes, N., Jahre, M. & Roussat, C. 2009. "Supply chain integration: the role of logistics service providers." *International Journal of Productivity and Performance Management 58(1)*: 71–91.

Forger, G. 1995. "UPS starts world's premiere cross-docking operations." *Modern Materials Handling* (*November)*: 36–38.

Forouharfard, S. & Zandieh, M. 2010. "An imperialist competitive algorithm to schedule of receiving and shipping trucks in cross-docking systems." *The International Journal of Advanced Manufacturing Technology 51(9)*: 1179–1193.

Goetschalckx, M. & Jacobs-Blecha, C. 1989. "The vehicle routing problem with backhauls." *European Journal of Operational Research 42(1)*: 39–51.

Gotzamani, K., Longinidis, P. & Vouzas, F. 2010. "The logistics services outsourcing dilemma: Quality management and financial performance perspectives." *Supply Chain Management: An International Journal 15(6)*: 438–453.

Gu, J., Goetschalckx, M. & McGinnis, L.F. 2007. "Research on warehouse operation: A comprehensive review." *European Journal of Operational Research 177(1)*: 1–21.

Gu, J., Goetschalckx, M. & McGinnis, L.F. 2010. "Research on warehouse design and performance evaluation: A comprehensive review." *European Journal of Operational Research 203(3)*: 539–549.

Gue, K. R. 1999. "The effects of trailer scheduling on the layout of freight terminals." *Transportation Science 33(4)*: 419–428.

Gue, K. R. 2007. "Warehouses without inventory." *International Commerce Review 7(2)*: 124–132.

Gümüs, M. & Bookbinder, J. 2004. "Cross-docking and its implication in location-distribution systems." *Journal of Business Logistics 25(2)*: 199–228.

Hauser, K. & Chung, C.H. 2006. "Genetic algorithms for layout optimization in crossdocking operations of a manufacturing plant." *International Journal of Production Research 44(21)*: 4663–4680.

Helo, P. & Szekely, B. 2005. "Logistics information systems: An analysis of software solutions for supply chain co-ordination." *Industrial Management & Data Systems 105(1)*: 5–18.

Hernández, S., Peeta, S. & Kalafatas, G. 2011. "A less-than-truckload carrier collaboration planning problem under dynamic capacities." *Transportation Research Part E: Logistics and Transportation Review 47(6)*: 933–946.

Hingley, M., Lindgreen, A., Grant, D. B. & Kane, C. 2011. "Using fourth-party logistics management to improve horizontal collaboration among grocery retailers." *Supply Chain Management: An International Journal 16(5)*: 316–327.

Hu, Z-H., Zhao, Y. & Choi, T-M. 2013. "Vehicle routing problem for fashion supply chains with cross-docking." *Mathematical problems in Engineering: 1–10*.

Huemer, L. 2012. "Unchained from the chain: Supply management from a logistics service provider perspective." *Journal of Business Research 65(2)*: 258–264.

Jayaraman, V. & Ross, A. 2003. “A simulated annealing methodology to distribution network design and management.” *European Journal of Operational Research 144(3)*: 629–645.

Joo, C. & Kim, B. 2013. “Scheduling compound trucks in multi-door cross-docking terminals.” *The International Journal of Advanced Manufacturing Technology 64(5-8)*: 977–988.

Kärkkäinen, M., Laukkanen, S., Sarpola, S. & Kemppainen, K. 2007. “Roles of interfirm information systems in supply chain management.” *International Journal of Physical Distribution & Logistics Management 37(4)*: 264–286.

Klaas-Wissing, T. & Albers, S. 2010. “Cooperative versus corporate governance of LTL networks.” *International Journal of Logistics: Research and Applications 13(6)*: 493–506

Konur, D. & Golias, M. 2013a. “Analysis of different approaches to cross-dock truck scheduling with truck arrival time uncertainty.” *Computers and Industrial Engineering 65(4)*: 663–672.

Konur, D. & Golias, M. 2013b. “Cost-stable truck scheduling at a cross-dock facility with unknown truck arrivals: A meta-heuristic approach.” *Transportation Research Part E: Logistics and Transportation Review 49(1)*: 71–91.

Krajewska, M., Kopfer, H., Laporte, G., Ropke, S. & Zaccour G. 2008. “Horizontal cooperation among freight carriers: Request allocation and profit sharing.” *Journal of the Operational Research Society 59(11)*: 1483–1491.

Lambert, D. M., Cooper, M. C. & Pagh, J. D. 1998. “Supply chain management: implementation issues and research opportunities.” *International Journal of Logistics Management 9(2)*: 1–20.

Larbi, R., Alpan, G., Baptiste, P. & Penz, B. 2011. “Scheduling cross docking operations under full, partial and no information on inbound arrivals.” *Computers & Operations Research 38(6)*: 889–900.

Larsen, A., Madsen, O. & Solomon, M. M. 2002. “Partially dynamic vehicle routing-models and algorithms.” *Journal of the Operational Research Society 53(6)*: 637–646.

Laudon, K. & Laudon, J. 2010. *Management information systems: Managing the digital firm,* Pearson: Upper Saddle River, NJ, USA.

Law, A. M. & Kelton, W. D. 2000. *Simulation modeling and analysis*, McGraw Hill: Boston, MA, USA.

Lee, Y. H., Jung, J. W. & Lee, K. M. 2006. "Vehicle routing scheduling for cross-docking in the supply chain." *Computers & Industrial Engineering 51(2)*: 247–256.

Lemoine, W. & Dagnaes, L. 2003. "Globalisation strategies and business organisation of a network of logistics service providers." *International Journal of Physical Distribution & Logistics Management 33(3)*: 209–228.

Li, Y., Lim, A. & Rodrigues, B. 2004. "Crossdocking: JIT Scheduling with time windows." *The Journal of the Operational Research Society 55(12)*: 1342–1351.

Liao, C-J., Lin, Y. & Shih, S. C. 2010. "Vehicle routing with cross-docking in the supply chain." *Expert Systems with Applications 37(10)*: 6868–6873.

Liao, T., Egbelu, P. J. & Chang, P. 2012. "Two hybrid differential evolution algorithms for optimal inbound and outbound truck sequencing in cross docking operations." *Applied Soft Computing 12(11)*: 3683–3697.

Liao, T., Egbelu, P. J. & Chang, P. 2013. "Simultaneous dock assignment and sequencing of inbound trucks under a fixed outbound truck schedule in multi-door cross docking operations." *International Journal of Production Economics 141(1)*: 212–229.

Lim, A., Miao, Z., Rodrigues, B. & Xu, Z. 2005. "Transshipment through crossdocks with inventory and time windows." *Naval Research Logistics 52(8)*: 724–733.

Lix, L. M., Keselman, J. C. & Keselman, H. J. 1996. "Consequences of assumption violations revisited: A quantitative review of alternatives to the one-way analysis of variance F test." *Review of educational research 66(4)*: 579–619.

Lopez, J. 2013. *Intra-enterprise collaborative planning with transshipments,* MSc thesis, University of Groningen.

Luo, G. & Noble, J. S. 2012. "An integrated model for crossdock operations including staging." *International Journal of Production Research 50(9)*: 2451–2464.

Ma, H., Miao, Z., Lim, A. & Rodrigues, B. 2011. "Crossdocking distribution networks with setup cost and time window constraint." *Omega 39(1)*: 64–72.

Marchet, G., Perotti, S. & Mangiaracina, R. 2012. "Modelling the impacts of ICT adoption for inter-model transportation." *International Journal of Physical Distribution & Logistics Management 42(2)*: 110–127.

Marjani, M. R., Husseini, S. M. M. & Karimi, B. 2012. "Bi-objective heuristics for multi-item freights distribution planning problem in crossdocking networks." *The International Journal of Advanced Manufacturing Technology 58(9-12)*: 1201–2016.

Mason, S., Ribera, P., Farris, J. & Kirk, R. 2003. "Integrating the warehousing and transportation functions of the supply chain." *Transportation Research Part E: Logistics and Transportation Review 39(2)*: 141–159.

Mason, R., Lalwani, C. & Boughton, R. 2007. "Combining vertical and horizontal collaboration for transport optimization." *Supply Chain Management: An International Journal 12(3)*: 187–199.

Masson, R., Lehuédé, F. & Péton, O. 2013. "An adaptive large neighborhood search for the pickup and delivery problem with transfers." *Transportation Science 47(3)*: 344–355.

McWilliams, D. L. 2009a. "A dynamic load-balancing scheme for the parcel hub-scheduling problem." *Computers & Industrial Engineering 57(3)*: 958–962.

McWilliams, D. L. 2009b. "Genetic-based scheduling to solve the parcel hub scheduling problem." *Computers & Industrial Engineering 56(4)*: 1607–1616.

McWilliams, D. L. 2010. "Iterative improvement to solve the parcel hub scheduling problem." *Computers & Industrial Engineering 59(1)*: 136–144.

McWilliams, D. L. & McBride, M. E. 2012. "A beam search heuristics to solve the parcel hub scheduling problem." *Computers & Industrial Engineering 62(4)*: 1080–1092.

McWilliams, D. L., Stanfield, P. M. & Geiger, C. D. 2005. "The parcel hub scheduling problem: A simulation-based solution approach." *Computers & Industrial Engineering 49(3)*: 393–412.

McWilliams, D. L., Stanfield, P. M. & Geiger, C. D. 2008. "Minimizing the completion time of the transfer operations in a central parcel consolidation terminal with unequal-batch-size inbound trailers." *Computers & Industrial Engineering 54(4)*: 709–720.

Meller R. D., Montreuil B., Thivierge C. & Montreuil Z. 2012. "Functional design of physical internet facilities: A road-based transit center." In Carrano *et al.* (Ed.) *Progress in Material Handling Research (347–378)*, Gardanne, FR.

Melo, M., Nickel, S. & Da Gama, F. S. 2009. "Facility location and supply chain management: A review." *European Journal of Operational Research 196(2)*: 401–412.

Miao, Z., Lim, A. & Ma, H. 2009. "Truck dock assignment problem with operational time constraint within crossdocks." *European Journal of Operational Research 192(1)*: 105–115.

Miao, Z., Yang, F., Fu, K. & Xu, D. 2012. "Transshipment service through crossdocks with both soft and hard time windows." *Annals of Operations Research 192(1)*: 21–47.

Miles, H. & Huberman, M. 1994. *Qualitative data analysis: A sourcebook*, Sage Publications: Beverly Hills, CA, USA.

Mitrovic-Minic, S. & Laporte, G. 2006. "The pickup and delivery problem with time windows and transshipment." *INFOR: Information Systems and Operational Research 44(3)*: 217–228

Montreuil, B. 2011. "Toward a Physical Internet: meeting the global logistics sustainability grand challenge." *Logistics Research 3*(2-3): 71–87.

Mousavi S. M. & Moghaddam, R. T. 2013. "A hybrid simulated annealing algorithm for location and routing scheduling problems with cross-docking in the supply chain." *Journal of Manufacturing Systems 32(2)*: 335–347.

Musa, R., Arnaout, J-P. & Jung, H. 2010. "Ant colony optimization algorithm to solve for the transportation problem of cross-docking network." *Computers & Industrial Engineering 59(1)*: 85–92.

Nagy, G. & Salhi, S. 2005. "Heuristic algorithms for single and multiple depot vehicle routing problems with pickups and deliveries." *European Journal of Operational Research 162(1)*: 126–141.

Nagy, G., Wassan, N. A. & Salhi, S. 2013. "The vehicle routing problem with restricted mixing of deliveries and pickups." *Journal of Scheduling 16(2)*: 199–213.

Napolitano, M. 2000. *Making the Move to Cross Docking – A practical guide to planning, designing, and implementing a cross dock operation.* Warehousing Education and Research Council (WERC), Oak Brook, IL, USA.

Oh, Y., Hwang, H., Cha, C. N. & Lee, S. 2006. "A dock-door assignment problem for the Korean mail distribution center." *Computers & Industrial Engineering 51(2)*: 288–296.

Parragh, S., Doerner, K. & Hartl, R. 2006. "A survey on pickup and delivery models. Part II: Transportation between pickup and delivery locations." *Working paper*, University of Vienna.

Parragh, S., Doerner, K. & Hartl, R. 2008. "A survey on pickup and delivery problems. Part I: Transportation between customers and depot." *Journal für Betriebswirtschaft 58(1)*: 21–51.

Perego, A., Perotti, S. & Mangiaracina, R. 2011. "ICT for logistics and freight transportation: A literature review and research agenda." *International Journal of Physical Distribution & Logistics Management 41(5)*: 457–483.

Physical Internet Manifesto. 2012. http://physicalinternetinitiative.org Last consulted April 10th 2014.

Pillac, V., Gendreau, M., Guéret, C. & Medaglia, A. L. 2013. "A review of dynamic vehicle routing problems." *European Journal of Operational Research 225(1)*: 1–11.

Power, D. 2005. "Supply chain management integration and implementation: A literature review." *Supply Chain Management: An International Journal 10(4)*: 252–263.

Pramatari, K. 2007. "Collaborative supply chain practices and evolving technological approaches." *Supply Chain Management: An International Journal 12(3)*: 210–220

Rais, A., Alvelos, F. & Carvalho, M. S. 2014. "New mixed integer-programming model for the pickup-and-delivery problem with transshipment." *European Journal of Operational Research 235(3)*: 530–539.

Ropke, S. & Pisinger, D. 2006a. "An adaptive large neighborhood search heuristic for the pickup and delivery problem with time windows." *Transportation Science 40(4)*: 455–472.

Ropke, S. & Pisinger, D. 2006b. "A unified heuristic for a large class of vehicle routing problems with backhauls." *European Journal of Operational Research 171(3)*: 750–775.

Rosales, C. R., Fry, M. J. & Radhakrishnan, R. 2009. "Transfreight reduces costs and balances workload at Georgetown crossdock." *Interfaces 39(4)*: 316–328.

Robinson, S. 2004. *Simulation: The Practice of Model Development and Use*, John Wiley & Sons: Chichester, UK.

Ross, A. & Jayaraman, V. 2008. "An evaluation of new heuristics for the location of cross-docks distribution centers in supply chain network design." *Computers & Industrial Engineering 55(1)*: 64–79.

Rouwenhorst, B., Reuter, B., Stockrahm, V., van Houtum, G., Mantel, R. & Zijm, W. 2000. "Warehouse design and control: Framework and literature review." *European Journal of Operational Research 122(3)*: 515–533.

Saddle Creek Logistics Services. 2008. "2008 Cross-docking trends report". Available from http://www.sclogistics.com/news-resources/white-papers.

Saddle Creek Logistics Services. 2011. "2011 Cross-docking trends report". Available from http://www.sclogistics.com/news-resources/white-papers.

Santos, F. A., Mateus, G. R. & Cunha, A. S. 2013. "The pickup and delivery problem with cross-docking. " *Computers & Operations Research 40(4)*: 1085–1093.

Sarraj, R., Ballot, E., Pan, S., Hakimi, D. & Montreuil, B. 2014. "Interconnected logistic networks and protocols: simulation-based efficiency assessment." *International Journal of Production Research 52(11)*: 3185–3208.

Savelsbergh, M. & Sol, M. 1995. "The general pickup and delivery problem." *Transportation Science 29(1)*: 17–29.

Schmoltzi, C. & Wallenburg, C. 2011. "Horizontal cooperation between logistics service providers: Motives, structure, performance." *International Journal of Physical Distribution & Logistics Management 41(6)*: 552–576.

Schmoltzi, C. & Wallenburg, C. 2012. "Operational governance in horizontal cooperations of logistics service providers: Performance effects and the moderating role of cooperation complexity." *Journal of Supply Chain Management 48(2)*: 53–74.

Schwind, M., Gujo, O. & Vykoukal, J. 2009. "A combinatorial intra-enterprise exchange for logistics services." *Information Systems and e-Business Management 7(4)*: 447–471.

Selviaridis, K. & Spring, M. 2007. "Third party logistics: A literature review and research agenda." *International Journal of Logistics Management 18(1)*: 125–150.

Shakeri, M., Low, M. Y. H., Turner, S .J. & Lee, E. W. 2012. "A robust two-phase heuristic algorithm for the truck scheduling problem in a resource-constrained crossdock." *Computers & Operations Research 39(11)*: 2564–2577.

Simatupang, T. M. & Sridharan, R. 2002. "The collaborative supply chain." *International Journal of Logistics Management 13(1):* 15–30.

Solomon, M. M. 1987. "Algorithms for the vehicle routing and scheduling problems with time window constraints." *Operations Research 35(2)*: 254–265.

Soltani, R. & Sadjadi, S. J. 2010. "Scheduling trucks in cross-docking systems: A robust meta-heuristics approach." *Transportation Research Part E: Logistics and Transportation Review 46(5)*: 650–666.

Stalk, G., Evens, P. & Shulman, L. E. 1992. "Competing on capabilities: The new role of corporate strategy." *Harvard Business Review 70(2)*: 57–69.

Stank, T. & Goldsby, T. 2000. "A framework for transportation decision making in an integrated supply chain." *Supply Chain Management: An International Journal 5(2)*: 71–77.

Stefansson, G. 2006. "Collaborative logistics management and the role of third-party service providers." *International Journal of Physical Distribution & Logistics Management 36(2)*: 76–92.

Stephan, K. & Boysen, N. 2011a. "Cross-docking." *Journal of Management Control 22(1)*: 129–137.

Stephan, K. & Boysen, N. 2011b. "Vis-à-vis vs. mixed dock door assignment: A comparison of different cross dock layouts." *Operations Management Research 4(3-4)*: 150–163.

Sung, C. S. & Song, S. H. 2003. "Integrated service network design for a cross-docking supply chain network." *The Journal of the Operational Research Society 54(12)*: 1283–1295.

Sung, C. S. & Yang, W. 2008. "An exact algorithm for a cross-docking supply chain network design problem." *The Journal of the Operational Research Society 59(1)*: 119–136.

Tarantilis, C. D. 2013. "Adaptive multi-restart tabu search algorithm for the vehicle routing problem with cross-docking." *Optimization letters 7(7)*: 1583–1596.

Tang, S.-L. & Yan, H. 2010 "Pre-distribution vs. post-distribution for cross-docking with transshipments." *Omega 38(3)*: 192–202.

Topteam Logistiek. 2011. "Partituur naar de top." *Technical report (In Dutch)* Retrieved from http://www.rijksoverheid.nl/documenten-en-publicaties/rapporten/2011/06/17/partituur-naar-de-top.html Last consulted April 2014.

Tsui, L. Y. & Chang, C-H. 1990. "A microcomputer based decision support tool for assigning dock doors in freight yards." *Computers & Industrial Engineering 19(1-4)*: 309–312.

Tsui, L. Y. & Chang, C-H. 1992. "An optimal solution to a dock door assignment problem." *Computers & Industrial Engineering 23(1-4)*: 283–286.

Vahdani, B., Soltani, R. & Zandieh, M. 2010. "Scheduling the truck holdover recurrent dock cross-dock problem using robust meta-heuristics." *The International Journal of Advanced Manufacturing Technology 46(5-8)*: 769–783.

Vahdani, B., Tavakkoli-Moghaddam, R., Zandieh, M. & Razmi, J. 2012. "Vehicle routing scheduling using an enhanced hybrid optimization approach." *Journal of Intelligent Manufacturing 23(3)*: 759–774.

Vahdani, B. & Zandieh, M. 2010. "Scheduling trucks in cross-docking systems: Robust meta-heuristics." *Computers & Industrial Engineering 58(1)*: 12–24.

Van Belle, J. & Valckenaers, P., Cattrysse, D. 2012. "Cross-docking: State of the art." *Omega 40(6)*: 827–846.

Van Belle, J., Valckenaers, P., Vanden Berghe, G. & Cattrysse, D. 2013. "A tabu search approach to the truck scheduling problem with multiple docks and time windows." *Computers & Industrial Engineering 66(4)*: 818–826.

Van Blommestein, F. 2013. *Structured communication for dynamic business – an architecture for flexible B2B communication*, PhD thesis, University of Groningen.

Van der Vaart, T. & Van Donk, D. 2008. "A critical review of survey-based research in supply chain integration." *International Journal of Production Economics 111(1)*: 42–55.

Vis, I. F. A. & Roodbergen, K. J. 2011. "Layout and control policies for cross docking operations." *Computers & Industrial Engineering 61(4)*: 911–919.

Vis, I. F. A. & Roodbergen, K. J. 2008. "Positioning of goods in a cross-docking environment." *Computers & Industrial Engineering 54(3)*: 677–689.

Vogt, J. J. 2010. "The successful cross-dock based supply chain." *Journal of Business Logistics 31(1)*: 99–119.

Voss, C., Tsikriktsis, N. & Frohlich, M. 2002. "Case research in operations management." *International Journal of Operations & Production Management 22(2)*: 195–219.

Wallenburg, C. & Raue, J. 2011. "Conflict and its governance in horizontal cooperations of logistics service providers." *International Journal of Physical Distribution & Logistics Management 41(4)*: 385–400.

Wang, J-F. & Regan, A. 2008. "Real-time trailer scheduling for crossdock operations." *Transportation Journal 47(2)*: 5–20.

Wang, X. & Kopfer, H. 2013. "Collaborative transportation planning of less-than-truckload freight." *OR Spectrum 36(2)*: 357–380.

Wasner, M. & Zäpfel, G. 2004. "An integrated multi-depot hub-location vehicle routing model for network planning of parcel service." *International Journal of Production Economics 90(3)*, 403–419.

Wen, M., Larsen, J., Clausen, J., Cordeau, J-F. & Laporte, G. 2009. "Vehicle routing with cross-docking." *The Journal of the Operational Research Society 60(12)*: 1708–1718.

Witt, C. E. 1998. "Crossdocking: Concepts demand choice." *Material Handling Engineering 53(7)*: 44–49.

Wortmann, J. C., Alblas, A., Buijs, P. & Peters, K. 2013. "Supply chain integration for sustainability faces sustaining ICT problems." in Prabhu *et al.* (Eds.) *Advances in Production Management Systems (493–500)*, Springer, Heidelberg, DE.

Yan, H. & Tang, S-L. 2009. "Pre-distribution and post-distribution cross-docking operations." *Transportation Research Part E: Logistics and Transportation Review 45(6)*: 843–859.

Yang, K. K., Balakrishnan, J. & Cheng, C. H. 2010. "An analysis of factors affecting cross-docking operations." *Journal of Business Logistics 31(1)*: 121–148.

Yin, R. K. 1994. *Case study research: Design and methods (2nd ed.)*, Sage: Newbury Park, CA, USA.

Yu, W. & Egbelu, P. J. 2008. "Scheduling of inbound and outbound trucks in cross docking systems with temporary storage." *European Journal of Operational Research 184(1)*: 377–396.

Yu, V. F., Sharma, D. & Murty, K. G. 2008. "Door allocations to origins and destinations at less-than-truckload trucking terminals." *Journal of Industrial and Systems Engineering 2(1)*: 1–15.

Zacharia, Z. G., Sanders, N. R., Nix, N. W. 2011. "The Emerging Role of the Third-Party Logistics Provider (3PL) as an Orchestrator." *Journal of Business Logistics 32(1)*, 40–54.

Zäpfel, G. & Wasner, M. 2002. "Planning and optimization of hub-and-spoke transportation networks of cooperative third-party logistics providers." *International Journal of Production Economics 78(2)*, 207–220.

Zhang, X., Van Donk, D. & Van der Vaart, T. 2011. "Does ICT influence supply chain management and performance?" *International Journal of Operations & Production Management 31(11):* 1215–1247.

Academic summary

The ecological, societal, and economic sustainability of logistics is one of today's major challenges and is increasingly deliberated by consumers, shippers, governmental organizations and logistics service providers alike. Achieving sustainable distribution logistics is complicated by the far-reaching globalization and specialization of supply chains and the advent of just-in-time strategies. These trends have led to ever more fragmented flows of goods between partners in the supply chain. In addition, consumers became accustomed to a choice from several distribution channels and expect short and reliable distribution lead-times for each channel. When operating in isolation, logistics service providers often face difficulties in meeting the logistics requirements that stem from these trends. For example, goods are often moved in partially loaded trailers or sitting idly in intermediary logistics facilities, such as distribution centers.

This thesis shows how collaboration among partners in the distribution network and with competitors offers opportunities to address the challenges associated with sustainable distribution logistics. Collaboration among partners acting at successive stages within the same distribution network is referred to as *vertical collaboration*. Cross-docking is an acknowledged strategy where partners collaborate vertically to improve the interconnectivity between their logistics activities and thereby reduce the in-process inventory and lead times associated with distribution logistics. Collaboration in distribution logistics can also occur among partners that are active at the same stage of the supply chain, e.g., among the shippers, carriers, or receivers of goods. This form of collaboration is referred as *horizontal collaboration*. Horizontal collaboration among road-freight carriers renders the opportunity to bundle flows of goods that would have been too thin to transport in fully loaded trailers when serviced by the carriers individually. This thesis studies horizontal and vertical collaboration in distribution networks with cross-docks and derives solution approaches for the challenges and opportunities therein. In identifying and developing new collaborative logistics solutions, the thesis adopts a multi-disciplinary research approach—integrating concepts from Operations Research, Information Systems, and Supply Chain Management.

Chapters 2 and 3 study horizontal collaboration between autonomous road-freight carriers. Prior research on that subject focused on strategic and tactical decision-making aspects of horizontal carrier collaboration and stressed the importance of appropriately selecting partners and setting up governance structures. This thesis complements those findings with understanding about operational decision-making aspects. It shows that carriers rely upon partners for the execution of a considerable part of their transportation services. Nevertheless, the corresponding operational planning and control decisions are seldom made jointly.

Chapter 2 addresses the role of IT in joint operational decision-making among horizontally collaborating carriers. It reveals that the challenges carriers face in that regard exist—despite the broad availability of state-of-the-art IT. A typology is proposed that explains how inherent technological differences between types of IT applications result in IT integration issues that hinder joint planning and control among collaborating carriers. At each carrier individually, such IT integration issues appear when updating a transportation management system with the constantly changing information gathered by fleet telematics and route planning systems. Among collaborating carriers, IT systems are integrated through XML and EDI technologies, which connect transportation management systems alone. Exchanging information from fleet telematics and route planning systems through these IT connections is far from trivial; whereas such information is needed to jointly plan and control collaborative transport operations. Accordingly, Chapter 2 stresses that any expectations with regard to XML and EDI-based IT integration for improving joint operational planning and control should be considered with care. Moreover, Chapter 2 reveals that breakthrough IT innovations are needed to support joint operational decision-making among collaborating carriers.

Chapter 3 studies the collaboration between two autonomous business units of a Dutch logistics service provider and proposes alternatives to further improve their collaborative transport operations. Originally, each business unit operated its own depot with a fleet of vehicles to pick up and deliver loads throughout The Netherlands. As a result of their collaboration, a new network configuration emerged, in which both depots and fleets of vehicles can be used. The joint network configuration results in several collaborative planning challenges, such as deciding whether or not a load is routed via one or both depots. Chapter 3 describes the academic state-of-the-art in pickup and delivery problems and shows that the integration of the individual network configurations leads to new modelling challenges that are not yet addressed in the literature. A heuristic is proposed that supports the collaborative transport planning by determining which loads are to be transferred between depots prior to delivery at their final destination. Experiments with a full year of operational data from the business units under study show that the heuristic can reduce the total travel distance of delivery routes with 24% compared to the situation without collaboration.

Chapters 4 and 5 study vertical collaboration between supply chain partners in distribution networks with cross-docks. Cross-docking is a popular logistics strategy in industry as it can reduce distribution costs and enhance the responsiveness of distribution networks. It aims to create a seamless flow of goods from shipper to receiver by applying the just-in-time philosophy to distribution logistics. In cross-docking, economies in transportation costs are realized by operating full truckloads through the distribution network without the need for long-term storage in intermediary logistics facilities. Inside a cross-dock facility, goods are either moved directly from inbound to outbound trailers or placed on the ground for a very short amount of time. This thesis illustrates how the absence of storage buffers in distribution networks with cross-docks results in strong interdependencies between local cross-dock operations and network-wide logistics. In line with the just-in-time nature of the cross-docking strategy, the need for a network orientation is stressed.

Chapter 4 lists the individual decision problems faced by cross-dock managers in industry and links those problems to the mathematical models proposed in academic cross-docking literature. Collectively, this list of individual decision problems reflects the full scope of the design and coordination of cross-docking operations. The individual problems are clustered in six problem classes according to their decision-making level (i.e., strategic, tactical, operational) and whether they address a local cross-dock problem or a problem at the network level. Due to the absence of a storage buffers, cross-dock mangers are faced with many interdependencies among individual problems—especially among local and network-wide cross-docking problems. A general classification of academic cross-docking models shows that those interdependencies are hardly considered in the literature. Rather, most models proposed in literature consider only local cross-dock operations. Chapter 4 proposes a framework that specifies the interdependencies between the cross-docking problem classes by describing their input/output characteristics. The research classification and framework can be used to develop new mathematical models and IT applications aimed at synchronizing local cross-dock operations and network-wide logistics.

Chapter 5 studies the interdependencies between local cross-dock operations and network-wide logistics in the distribution network of an international grocery retailer. It illustrates how changes in the arrangement of loads inside inbound trailers and their arrival time at the cross-dock directly affect the time, material handling, and space required to assemble loads for outbound trailers. Two changes to the retailer's current cross-docking design and coordination are proposed for the purpose of improving overall distribution logistics performance. The first change entails a new local cross-dock planning policy that assigns dock doors to inbound and outbound trailers—while carefully considering the constraints that stem from distribution network planning. The second change involves a minor distribution network re-design, which facilitates the arrival of sorted inbound trailer loads at the cross-dock. A simulation models is designed to compare and evaluate the performance effects of the proposed changes against the current operations at the retailer. The simulation results show that the proposed local planning policy reduces the internal travel distance of goods through the cross-dock with 42%, which strongly improves material handling efficiency. The proposed distribution network re-design renders the opportunity to postpone the arrival of inbound goods at the cross-dock. As a result, the average volume of unprocessed goods reduces with 20%, while also the total volume of goods on-site reduces significantly. Accordingly, the utilization of the cross-dock facility improved, which avoids the need for capacity expansions at higher freight volumes.

In conclusion, the research projects presented in this thesis contribute to the sustainability of distribution logistics. Due to their exploratory nature, the studies presented in this thesis form the starting point for future research on horizontal and vertical collaboration in distribution networks with cross-docks. The chapters on horizontal collaboration among autonomous freight carriers specify the challenges and opportunities for joint operational planning and control of collaborative transportation. Accordingly, these chapters may encourage scholars and practitioners to develop and test new planning procedures, heuristics and dedicated IT applications, while carefully considering the role of the human planner in that regard. The chapters on vertical collaboration in distribution networks with cross-docks emphasize the need for a network orientation in cross-docking and pinpoint the lack thereof in current research and practice. In particular, opportunities for future research reside in developing cross-docking design and coordination policies that aim to synchronize local cross-dock operations and network-wide logistics.

Nederlandse samenvatting

De logistieke sector staat voor grote uitdagingen op het gebied van ecologische, maatschappelijke en economische duurzaamheid. Consumenten, producenten, overheden en logistiek dienstverleners hebben dan ook steeds meer aandacht voor duurzame logistiek. De duurzaamheid van distributielogistiek wordt bemoeilijkt door verregaande mondialisering en supply chain specialisatie en door de opkomst van just-in-time productie. Deze trends hebben ertoe geleid dat zendingen tussen partners in supply chains steeds kleiner zijn geworden en met steeds striktere tijdsrestricties bij de klant moeten worden afgeleverd. Daarnaast verwacht de consument bij aanschaf van een product te kunnen kiezen uit verschillende distributiekanalen. Ze rekent daarbij op korte, betrouwbare levertijden voor elk distributiekanaal. Als gevolg van de hierboven beschreven trends, hebben veel logistiek dienstverleners moeite om op duurzame wijze te voldoen aan de wensen van de klant. Zo worden goederen vaak vervoerd in gedeeltelijk geladen vrachtwagens of liggen producten nodeloos lang op voorraad in distributiecentra.

Dit proefschrift laat zien hoe samenwerking tussen partners in de distributieketen en met concurrenten daarbuiten kansen biedt om de duurzaamheid van distributielogistiek te verbeteren. Samenwerking tussen partners in opeenvolgende stadia van de distributieketen wordt ook wel *verticale samenwerking* genoemd. Cross-docking is daarbij een erkende strategie waarin partners hun logistieke processen op elkaar afstemmen om op die manier de voorraden in de distributieketen te verminderen en de levertijden te verkorten. Samenwerking in distributielogistiek kan ook ontstaan tussen mogelijk concurrerende bedrijven die vergelijkbare activiteiten in verschillende distributieketens uitvoeren, zoals bijvoorbeeld tussen verladers, vervoerders, of ontvangers van goederen. Deze vorm van samenwerking wordt ook wel *horizontale samenwerking* genoemd. Dit proefschrift richt zich op horizontale en verticale samenwerking in distributienetwerken met cross-docks en bestudeert methoden waarmee bedrijven hun logistieke middelen efficiënter en duurzamer kunnen inzetten. Daarvoor wordt een multidisciplinaire onderzoeksaanpak gehanteerd, waarbij concepten uit de vakgebieden *informatiesystemen*, *Operations Research* en *Supply Chain Management* worden gecombineerd.

Hoofdstukken 2 en 3 richten zich op horizontale samenwerking in wegtransport. Eerder onderzoek binnen dat thema biedt vooral inzicht in strategische en tactische besluitvormingsprocessen. Het benadrukt hoe belangrijk het is om de juiste partners te vinden en om gedegen organisatiestructuren te ontwerpen en implementeren. Dit proefschrift vormt een aanvulling op eerder onderzoek door inzichten te presenteren op het gebied van operationele besluitvorming. Het toont aan dat transporteurs geregeld een beroep doen op hun partners voor het vervoeren van hun zendingen. Desondanks worden de operationele plannings- en beheersbeslissingen aangaande het transport van die zendingen zelden gezamenlijk genomen.

Hoofdstuk 2 gaat in op de rol van ICT in gezamenlijke operationele besluitvorming tussen samenwerkende transporteurs. Hieruit blijkt dat transporteurs daarin, ondanks de brede beschikbaarheid van ICT, grote uitdagingen ondervinden. De in dit hoofdstuk voorgestelde typologie voor ICT applicaties biedt uitleg. Deze typologie maakt gebruik van gedetailleerde technologische karakteristieken van ICT om verschillende typen applicaties te onderscheiden. Het laat zien dat inherente technologische verschillen tussen die typen leiden tot ICT integratieproblemen die gezamenlijk planning en beheersing belemmeren. Binnen één autonome planningsafdeling leiden ICT integratieproblemen tot moeilijkheden bij het updaten van het transportmanagementsysteem met constant veranderende informatie uit voertuigvolgsystemen en rit- en routeplanningsoftware. Koppelingen tussen ICT van samenwerkende transporteurs wordt veelal bewerkstelligd door middel van XML en EDI technologieën. Dergelijke koppelingen sluiten alleen transportmanagement-systemen op elkaar aan. De uitwisseling van real-time informatie uit voertuig-volgsystemen en rit- en routeplanningsoftware via dergelijke ICT koppelingen is verre van triviaal—terwijl juist die informatie noodzakelijk is voor gezamenlijke transportplanning en -beheersing. Daarmee benadrukt hoofdstuk 2 dat voorzichtig moet worden omgesprongen met de verwachting dat moderne, op EDI en XML gebaseerde ICT koppelingen gezamenlijke operationele besluitvorming tussen transporteurs verbetert. Daarnaast pleit hoofdstuk 2 voor verregaande ICT ontwikkeling om samenwerkende transporteurs in de toekomst beter in staat te stellen gezamenlijk planningsbeslissingen te nemen.

Hoofdstuk 3 bestudeert de samenwerking tussen twee autonome transportdivisies van een logistiek dienstverlener. Ook worden voorstellen gedaan om die samenwerking te verbeteren. Oorspronkelijk transporteerde elk van de twee divisies ladingen door heel Nederland. Zij maakten daarbij alleen gebruik van hun eigen wagenpark en cross-dock. Door de samenwerking is een nieuwe netwerkconfiguratie ontstaan waarin beide divisies ook gebruik kunnen maken van elkaars wagenpark en cross-dock. Deze geïntegreerde netwerkconfiguratie leidt tot verschillende nieuwe uitdagingen in de transportplanning. Zo moet worden besloten of een lading al dan niet via één of beide cross-docks zal worden vervoerd. Hoofdstuk 3 beschrijft de huidige stand van de academische literatuur op het gebied van transportplanning. Het toont aan dat de integratie van netwerkconfiguraties van samenwerkende transporteurs leidt tot nieuwe modelleringsuitdagingen die nog niet in de literatuur zijn behandeld. De in dit hoofdstuk beschreven heuristiek ondersteunt gezamenlijke transportplanning door systematisch te bepalen hoeveel en welke ladingen het beste kunnen worden uitgewisseld tussen de transportdivisies voordat ze worden afgeleverd bij de klant. De heuristiek is getest door middel van experimenten waarbij gebruik is gemaakt van een volledig jaar aan data van beide transportdivisies. De experimenten tonen aan dat de heuristiek de totaal afgelegde afstand voor het afleveren van ladingen in Nederland met 24% kan verminderen ten opzichte van de situatie zonder samenwerking.

Hoofdstukken 4 en 5 richten zich op verticale samenwerking tussen partners in distributieketens met cross-docks. Cross-docking wordt veel toegepast in hedendaagse distributielogistiek omdat het de distributiekosten kan verlagen en tegelijkertijd de reactiesnelheid kan verbeteren. Deze, op just-in-time gebaseerde, strategie stelt bedrijven in staat om kleine zendingen gegroepeerd te vervoeren zonder dat daarvoor tussentijdse opslag nodig is. In een cross-dock worden goederen vaak direct van inkomende naar uitgaande vrachtwagens verplaatst. Dit proefschrift laat zien hoe het ontbreken van tussentijdse opslag resulteert in een sterke onderlinge afhankelijkheid tussen de interne cross-dock processen en de ingaande en uitgaande ketenlogistiek. Daarom moeten logistieke processen in opeenvolgende stadia van de distributieketen naadloos op elkaar aangesloten worden om cross-docking succesvol toe te passen.

In Hoofdstuk 4 worden de individuele beslissingen die cross-dock managers in de praktijk tegenkomen vergeleken met de wiskundige modellen uit de academische literatuur. Het overzicht van individuele beslisproblemen weerspiegelt het volledige spectrum van ontwerp- en aansturingsbeslissingen op het gebied van cross-docking. De individuele beslisproblemen zijn geclusterd in zes probleemklassen op basis van hun besluitvormingsniveau (d.w.z., strategisch, tactisch, of operationeel) en of het een intern cross-dock probleem of een ketenlogistiek probleem omvat. Door het ontbreken van tussentijdse opslag zijn er in de praktijk veel onderlinge afhankelijkheden tussen individuele beslisproblemen, met name tussen interne cross-dock processen en ketenlogistiek. Uit de in dit hoofdstuk beschreven classificatie van wiskundige cross-docking modellen blijkt dat dergelijke afhankelijkheden nauwelijks worden beschouwd in de academische literatuur. Integendeel, de wiskundige modellen zijn veelal gericht op interne cross-dock processen alleen. Hoofdstuk 4 presenteert een theoretisch raamwerk dat de onderlinge afhankelijkheden specificeert door de input/output karakteristieken van de verschillende probleemklassen te beschrijven. De classificatie en het theoretisch raamwerk kunnen worden gebruikt voor het ontwikkelen van nieuwe wiskundige modellen en ICT applicaties gericht op een betere afstemming tussen interne cross-dock processen en ketenlogistiek.

Hoofdstuk 5 bestudeert de onderlinge afhankelijkheden tussen interne cross-dock processen en ketenlogistiek in de distributieketen van een supermarktketen. Het hoofdstuk illustreert de grote invloed van veranderingen in de aankomsttijd en ladingopbouw van inkomende vrachtwagens op de tijd, material handling en ruimte die in het cross-dock nodig is om ladingen voor uitgaande vrachtwagens samen te stellen. Er worden twee veranderingen voorgesteld voor het huidige ontwerp en de aansturing van de cross-docking processen. Het doel is om de prestaties van de distributieketen als geheel te verbeteren. De eerste verandering betreft een nieuwe procedure voor het toewijzen van docks aan inkomende en uitgaande vrachtwagens. In die procedure worden de beperkingen die voortvloeien uit de transportplanning zorgvuldig in beschouwing genomen. De tweede verandering betreft een geringe aanpassing in de ketenlogistiek, waardoor ladingen gesorteerd bij het cross-dock kunnen aankomen. Een simulatiemodel is ontwikkeld om de effecten van de voorgestelde veranderingen te evalueren en te vergelijken met de huidige situatie van de retailer. De resultaten van de simulatiestudie tonen aan dat de voorgestelde lokale planningsprocedure de afstand die goederen afleggen tussen hun inbound- en outbounddock met 42% vermindert, waardoor de material handling efficiëntie sterk verbetert. De voorgestelde aanpassing in ketenlogistiek maakt het mogelijk om de aankomst van vrachtwagens op het cross-dock uit te stellen. Daardoor neemt het gemiddeld volume onderhanden werk met 20% af, terwijl ook het totale goederen-volume in het cross-dock sterk vermindert. Als gevolg wordt de huidige cross-dock faciliteit beter benut, waardoor er bij hogere goederenvolumes niet direct capaciteitsuitbreiding nodig is.

Tot slot: de in dit proefschrift gepresenteerde onderzoeksprojecten dragen bij aan de duurzaamheid van distributielogistiek. Vanwege hun exploratieve karakter, vormen de studies uit deze thesis slechts het begin van verder onderzoek naar horizontale en verticale samenwerking in distributieketens met cross-docks. De hoofdstukken over horizontale samenwerking in wegtransport bieden een gedetailleerde beschrijving van de uitdagingen en kansen op het gebied van gezamenlijke operationele besluitvorming tussen samenwerkende transporteurs. Daarbij hebben vooral innovatieve planningsprocedures, heuristieken en ICT toepassingen die specifiek gericht zijn op het ondersteunen van de transportplanning van samenwerkende transporteurs grote academische en praktische waarde. Ook de nieuwe rol van de planner in dergelijke gezamenlijke besluitvorming verdient meer aandacht. De hoofdstukken over verticale samenwerking tussen partners in distributieketens met cross-docks benadrukken de noodzaak van een ketenperspectief op cross-docking en duidt het gebrek daarvan aan in het bedrijfsleven en eerder onderzoek. Er liggen dan ook grote mogelijkheden voor toekomstig onderzoek in het ontwikkelen van ontwerp- en aansturingsmodellen gericht op een betere afstemming tussen interne cross-dock processen en ketenlogistiek.

Dankwoord

Graag wil ik alle mensen bedanken die een belangrijke rol hebben gespeeld in mijn periode als promovendus en zonder wie de totstandkoming van dit proefschrift niet mogelijk was geweest.

First of all, I want to thank Nick Szirbik, my co-supervisor. I met Nick as the teacher of systems engineering. I was blown away by his energy and enthusiasm during the classes. Later, during my MSc thesis project, it was Nick who inspired me to obtain a PhD position by bringing that same enthusiasm to our discussions about doing academic research. Nick, I am truly grateful for your involvement from the very start of my time as a PhD-candidate. I thoroughly enjoyed our daily conversations, during which I have learned so much—from writing academic papers and drawing up reviewer responses to aviation/aerospace and virtually all aspects of gastronomy, most notably Michelin star (or similar quality) food, wine, cheese and exotic coffees.

Ook gaat enorm veel dank uit naar mijn promotores, Hans Wortmann en Iris Vis. Hans, jij was er vanaf het begin bij. Je hebt me zien worstelen in de eerste helft van mijn promotietraject en hebt mij ook toen het vertrouwen gegeven in een goede afloop. Zelf was ik daar lang niet altijd zeker van. Jouw kennis van, en brede interesse in alles wat met ICT en logistiek te maken heeft, is aanstekelijk en biedt altijd inspiratie voor nieuwe onderzoeksprojecten. Ik heb enorme bewondering voor de manier waarop jij enthousiasme bij anderen weet los te maken en, binnen de vele projecten onder jouw hoede, de neuzen in dezelfde richting krijgt—en weet te houden. Ik hoop dat ik voldoende van jouw aanpak heb kunnen afkijken om dat in de toekomst zelf te kunnen toepassen in mijn werkzaamheden.

Iris, jouw benoeming tot hoogleraar in Groningen—en in het bijzonder je bereidheid om toe te treden tot mijn begeleidingsteam—markeert een kantelpunt in mijn promotietraject. Door jouw achtergrond en begeleiding ben ik mij steeds meer gaan richten op de logistieke sector. Die praktische context was precies wat nodig was om mijn onderzoek een belangrijke duw in de goede richting te geven. Bovenal wil ik mijn waardering uiten voor jouw altijd positieve en geïnteresseerde houding ten aanzien van mijn plannen en ideeën. Of het nu een plan voor een nieuwe publicatie betreft, een project met het bedrijfsleven, of een bepaalde invalshoek tijdens een presentatie, jij benadrukt altijd wat je er goed en interessant aan vindt en motiveert mij het plan verder uit te werken. Ik kijk ernaar uit om ook de komende jaren intensief met je samen te werken.

I would also like to thank the members of the assessment committee—Ruud Teunter, Jos van Hillgersberg and Benoit Montreuil—for carefully reading and assessing this thesis and for providing valuable comments to help improve my work.

Naast mijn (co-)promotores, heb ik het genoegen gehad met verschillende anderen aan onderzoeksprojecten en publicaties te werken. Met Gerben Meyer bestudeerde ik hoe het gebruik van *Intelligente Producten* de planning en beheersing van wegtransport kan verbeteren. De publicatie die daaruit voortvloeide was mijn eerste ervaring met het schrijven van een wetenschappelijk artikel. Van Gerbens ervaring en tips tijdens dat proces heb ik ook daarna nog veel profijt gehad. Kees Jan Roodbergen en Marjolein Veenstra waren belangrijk in het onderzoek naar de toepassing van wiskundige modellen in de rit- en routeplanning van samenwerkende transporteurs. Héctor Carlo encouraged me to continue my research on cross-docking. He helped me to understand even the most abstract models and co-authored a journal paper. My PhD position was co-funded by the EU, through the FP7 project ADVANCE. During that project, I met Philip Welch and Christopher Buckingham, with whom I visited many freight-carriers throughout the UK and worked on several projects. Chris, Phil, I will never forget our many interesting discussions over pints of beer—or glasses of wine—in Birmingham, Budapest, Milano, Brussels, and Amsterdam.

De studenten die ik heb mogen begeleiden bij hun BSc en MSc scriptieprojecten hebben een grote rol gespeeld in de totstandkoming van dit proefschrift. Sarah Nguyen en Bryan Huzen wil ik bedanken voor de professionele manier waarop zij de data hebben verzameld die als basis heeft gediend voor Hoofdstuk 2. Frans Rutten wil ik bedanken voor zijn werk bij logistiek dienstverlener *Wim Bosman*. Hans Danhof en Jose Lopéz zijn ook na het voltooien van hun scripties met tomeloos enthousiasme betrokken gebleven bij mijn onderzoek en het schrijven van artikelen. Hans, jouw scriptieproject is één groot succesverhaal gebleken. Ik bewonder de manier waarop jij, binnen een zeer complexe organisatie, jouw onderzoek precies zo hebt kunnen uitvoeren als wij dat voor ogen hadden. Jose, I thank you for all your efforts in our continuing research project with Fritom. The countless hours you have spent developing tools to clean and analyze Fritom's data yielded valuable insights in collaborative transportation management. Also, I enjoyed getting carried away in our talks about soccer.

Het empirsiche karakter van mijn proefschrift maakt dat ik sterk afhankelijk was van nieuwsgierige personen die hun bedrijf wilden openstellen. Ik prijs me dan ook bijzonder gelukkig met de vele enthousiaste en geïnteresseerde mensen die ik in het bedrijfsleven heb ontmoet. In het bijzonder wil ik Joris Wijnja en Tom Wiersma bedanken. Jullie hebben mij op de verschillende bedrijsflocaties altijd zeer gastvrij ontvangen en de bedrijfsvoering van Fritom in alle openheid toegelicht. Ik hoop dat we in de toekomst nog vele vruchten zullen plukken van onze samenwerking.

De collega's op de zesde verdieping—en de "RuG Matties" in het bijzonder—hebben een grote rol gespeeld in mijn werkplezier. Aline, Arjan, Bram, Carolien, Inge, Jasper, Justin, Kristian, Marcel, Marjolein, Minou, Monique, Nick, Nick, Oskar, Robbert-Jan, Simon en Tom. Bedankt dat ik altijd bij jullie terecht kan voor inhoudelijke vragen, maar vooral ook voor de vaak heerlijk zinlose gesprekken tijdens onze lunchwandelingen en andere nuttige onderbrekingen van ons werk.

Afleiding van mijn onderzoek vond ik op veel plekken, niet in de laatste plaats op roeivereniging Gyas. Ik wil alle roeiers en mede-coaches bedanken voor mijn dierbare herinneringen aan de vaak boeiende, intense trainingen en de vele spannende races. Mijn ploeggenoten van licht '06, Wim en alle andere vrienden die in de loop der jaren naar de Randstad zijn vertrokken, hoop ik, met het afronden van dit proefschrift, weer vaker te zullen gaan zien.

Tenslotte wil ik mijn familie en iedereen die ik als familie beschouw bedanken. Allereerst mijn lieve broertje en zusje. Jos, Mieke, hoewel wij elkaar niet wekelijks spreken, zijn jullie heel belangrijk voor me. Dolien, Jos, Paul en alle andere frequente bezoekers aan de Streek 40, bedankt voor de vele gesprekken en heerlijk musicale avonden. Anneke, Cor, Isabel, Roelof, Dianne, Sibren en Mathijs, bij jullie voel ik me altijd bijzonder welkom en thuis. Grote dank ben ik verschuldigd aan Marloes. Het plezier dat we samen hebben en de rust die jij mij geeft is van onschatbare waarde. Paps, mams, bedankt voor jullie onvoorwaardelijke steun en de mooie basis die jullie me hebben meegegeven. Eigenlijk kan ik mijn gevoel van dank en waardering niet in woorden vatten. Daarom draag ik dit proefschrift aan jullie op.

Biography

Paul Buijs (1985) received his Bachelor (BSc) and Master (MSc) in Industrial Engineering and Management from the *University of Groningen*—in 2009 and 2010. Subsequently, he obtained a full-time PhD candidate position in the Department of Operations at the Faculty of Economics and Business within the same university. From May through August 2014, Paul was a visiting researcher in the Faculty of Administration Sciences at *Université Laval*, Canada. During his PhD research, Paul participated in the EU FP7 project ADVANCE.

Paul's research interests are in the identification and design of innovative solutions for sustainable distribution logistics, particularly with regard to vertical and horizontal supply chain collaboration. To that end, he takes a multi-disciplinary research perspective—including concepts from Operations Research, Information Systems, and Supply Chain Management theory. His research is conducted in close cooperation with several large and smaller-sized companies requiring and/or providing logistics services throughout Europe. He intends to remain working in a position at the interface of research and practice in the future.

Paul authored and co-authored several journal and conference papers. He is first author of a journal paper in *Supply Chain Management: An International Journal* and another in the *European Journal for Operational Research*. Moreover, he co-authored a paper in the *International Journal of Operations & Production Management*. Conference papers appeared, amongst others, in *Information Control Problems in Manufacturing* (Vol. 14, No. 1, 2012) and *Progress of Material Handling Research* (2014). Prof. dr. ir. J.C. Wortmann, prof. dr. I.F.A. Vis, prof. dr. K.J. Roodbergen, dr. N.B. Szirbik, dr. G.G. Meyer, and dr. H.J. Carlo are among the co-authors of these papers.